1.1 A lightning bolt carrying 30,000 A lasts for 50 microseconds. If the lightning strikes an airplane flying at 20,000 feet, what is the charge deposited on the plane?

SOLUTION:

$I = 30{,}000\ A, \quad \Delta t = 50\mu s$

$Q = I\Delta t$

$Q = 30{,}000\ (50\mu)$

$Q = 1.5\ C$

1.2 If a 12-V battery delivers 100 J in 5 s, find (a) the amount of charge delivered and (b) the current produced.

SOLUTION:

$V = 12V$, $\Delta W = 100J$ in $5s$

a) $\Delta Q = \dfrac{\Delta W}{V} = \dfrac{100}{12}$

$\Delta Q = 8.33\ C$

b) $I = \dfrac{\Delta Q}{\Delta t} = \dfrac{8.33}{5}$

$I = 1.67A$

1.3 The current in a conductor is 3.5 A. How many coulombs of charge pass any point in a time interval of 2.5 min?

Solution:

1.3 $I = 3.5\ A \qquad \Delta t = 2.5\ min = 150\ s$

$Q = I(\Delta t) \qquad \boxed{Q = 525\ C}$

1.4 If 90 C of charge pass through an electric conductor in 30 seconds, determine the current in the conductor.

Solution:

1.4 $Q = 90C \quad \Delta t = 30S$

$$I = \frac{Q}{\Delta t} = \frac{90}{30} \quad \boxed{I = 3A}$$

1.5 **Determine the number of coulombs of charge produced by a 12-A battery charger in an hour.**

SOLUTION:

$I = 12A \quad , \quad \Delta t = 1hr = 60min$

$\Delta t = 3600\,s$

$Q = I\Delta t = 12(3600)$

$Q = 43.2\,KC$

1.6 Five coulombs of charge pass through the element in Fig. P1.6 from point A to point B. If the energy absorbed by the element is 150 J, determine the voltage across the element.

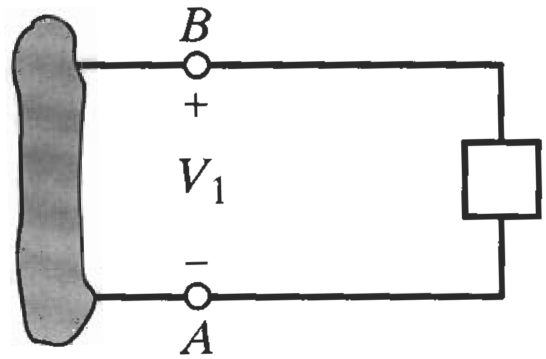
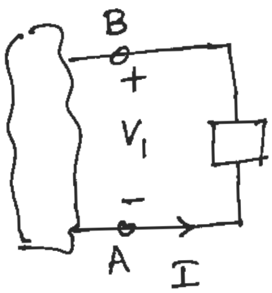


Figure P1.6

Solution:

1.6



$Q = 5\ C$

$W = 150\ J$

For passive sign convention: $W = -V_1 Q$

$$V_1 = -\frac{W}{Q} \qquad \boxed{V_1 = -30V}$$

1.7 The charge entering an element is shown in Fig. P1.7 Find the current in the element in the time interval $0 \leqq t \leqq 0.5$ s. [*Hint:* The equation for $q(t)$ is $q(t) = 1 + (1/0.5)t, t \geqq 0$.]

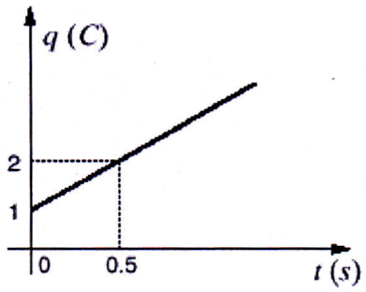


Figure P1.7

SOLUTION:

$$q(t) = 1+2t, \quad 0 \leqslant t \leqslant 0.5\text{s}$$

$$i(t) = \frac{dq(t)}{dt}$$

$$i(t) = 2\text{A}, \quad 0 \leqslant t \leqslant 0.5\text{s}$$

1.8 The current that enters an element is shown in Fig. P1.8. Find the charge that enters the element in the time interval $0 < t < 20$ s.

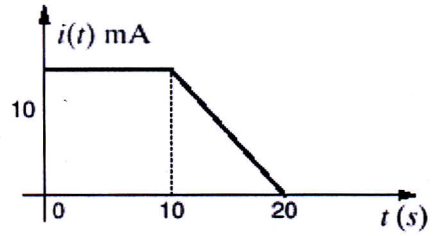


Figure P1.8

SOLUTION:

$$i(t) = m_1 t + b$$

$$m_1 = \frac{10-10}{10-20} = -1$$

$$i(t) = -t + b$$

$$10 = -10 + b$$

$$b = 20$$

$$i(t) = -t + 20 \text{ mA}$$

$$q(t) = \int_0^{20} i(t)\,dt$$

$$q(t) = \int_0^{10} 10 \times 10^{-3}\,dt + \int_{10}^{20} \frac{20-t}{1000}\,dt$$

$$q(t) = 10 \times 10^{-3} t \Big]_0^{10} + \frac{1}{1000}\left[20t - \frac{t^2}{2}\right]_{10}^{20}$$

$$q(t) = 0.1 + \frac{1}{1000}\left[20(20) - \frac{(20)^2}{2} - 20(10) + \frac{(10)^2}{2}\right]$$

$$q(t) = 0.1 + \frac{1}{1000}\left[200 - 200 + 50\right]$$

$$q(t) = 0.15\text{C}$$

1.9 The charge entering the positive terminal of an element is $q(t) = -30e^{-4t}$ mC. If the voltage across the element is $120e^{-2t}$V, determine the energy delivered to the element in the time interval $0 < t < 50$ ms.

SOLUTION:

$$q(t) = 30e^{-4t}\ mC$$

$$v(t) = 120e^{-2t}V$$

$$W = \int_{t1}^{t2} P\,dt = \int_{t1}^{t2} Vi\,dt$$

$$i(t) = \frac{dq(t)}{dt} = -4(-30)e^{-4t}mA$$

$$i(t) = 120\,e^{-4t}\,mA$$

$$W = \int_{t1}^{t2} (120e^{-2t})(120e^{-4t}m)\,dt$$

$$W = 14.4\int_{0}^{50m} e^{-6t}\,dt$$

$$W = 14.4\left[\frac{e^{-6t}}{-6}\right]^{50m}$$

$$W = 14.4\left[\frac{e^{-6(50m)}}{-6} + \frac{e^{-6(0)}}{6}\right]$$

$$W = 622.04\,mJ$$

1.10 The charge entering the positive terminal of an element is given by the expression $q(t) = -12e^{-2t}$ mC. The power delivered to the element is $p(t) = 2.4e^{-3t}$ W. Compute the current in the element, the voltage across the element, and the energy delivered to the element in the time interval $0 < t < 100$ ms.

SOLUTION:

$$q(t) = -12\,e^{-2t} \text{ mC}$$

$$p(t) = 2.4\,e^{-3t} \text{ W}$$

$$i(t) = \frac{dq(t)}{dt}$$

$$i(t) = 2(-12)e^{-2t} \text{ m}$$

$$i(t) = 24\,e^{-2t} \text{ mA}$$

$$W = \int_{t1}^{t2} p(t)\,dt = \int_0^{100m} 2.4\,e^{-3t}\,dt$$

$$W = \frac{2.4}{-3}{}^{-3t}\Big]_0^{100m}$$

$$W = \frac{2.4}{-3}\left[e^{-3(100m)} - e^{-3(0)}\right]$$

$$W = 207.35 \text{ mJ}$$

$$V(t) = \frac{P(t)}{i(t)}$$

$$V(t) = \frac{2.4\,e^{-3t}}{24\,e^{-2t}\,m}$$

$$V(t) = 100\,e^{-t} \text{ V}$$

1.11 The voltage across an element is $12e^{-2t}$ V. The current entering the positive terminal of the element is $2e^{-2t}$ A. Find the energy absorbed by the element in 1.5 s starting from $t = 0$.

SOLUTION:

$$V(t) = 12\, e^{-2t}\ \text{V}$$

$$i(t) = 2e^{-2t}\ \text{A}$$

$$W = ?\ ,\quad 0 - 1.5\,\text{s}$$

$$W = \int_{t1}^{t2} Vi\ dt$$

$$W = \int_0^{1.5} (12e^{-2t})(2e^{-2t})\, dt$$

$$W = \int_0^{1.5} 24e^{-4t}\, dt$$

$$W = \frac{24e^{-4t}}{-4}\Bigg]_0^{1.5}$$

$$W = -6e^{-4t}\Bigg]_0^{1.5} = -6e^{-4(1.5)} + 6e^{-4(0)}$$

$$W = 5.99\ \text{J}$$

1.12 The waveform for the current flowing into a circuit element is shown in Fig. P1.12. Calculate the amount of charge which enters the element between (a) 0 and 3 seconds, (b) 1 and 5 seconds, and (c) 0 and 6 seconds.

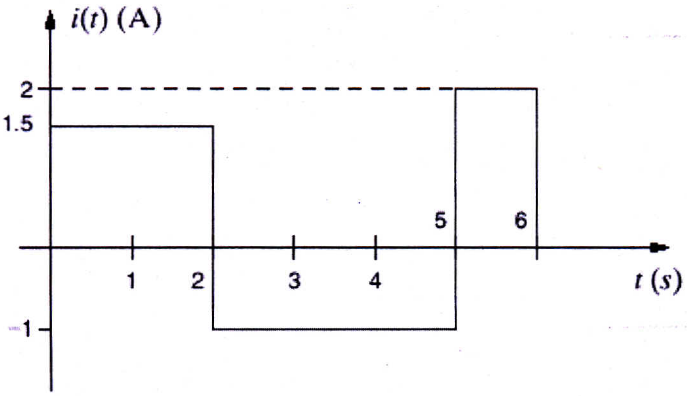


Figure P1.12

SOLUTION:

a) $q(t) = \int_{-\infty}^{t} i(x)\,dx$

$q(t) = \int_0^3 i(x)\,dx$

$q(t) = \int_0^2 1.5\,dx + \int_2^3 -1\,dx$

$q(t) = 1.5x\Big]_0^2 + -x\Big]_2^3$

$q(t) = 1.5(2) + [(-3) - (-2)]$

$q(t) = 3 - 3 + 2 = 2C$

b) $q(t) = \int_1^5 i(x)\,dx$

$q(t) = \int_1^2 1.5\,dx + \int_2^5 -1\,dx$

$q(t) = 1.5x\Big]_1^2 + (-x)\Big]_2^5$

$q(t) = [1.5(2) - 1.5(1)] + [-5 - (-2)]$

$q(t) = 1.5 - 5 + 2 = 1.5C$

c) $q(t) = \int_0^6 i(x)\,dx$

$$q(t) = \int_0^2 1.5\,dx + \int_2^5 -1\,dx + \int_5^6 2\,dx$$

$$q(t) = 1.5x\Big]_0^2 + (-x)\Big]_2^5 + 2x\Big]_5^6$$

$$q(t) = 1.5(2) + [-5-(-2)] + [2(6)-2(5)]$$

$$q(t) = 3 - 3 + 12 - 10$$

$$q(t) = 2C$$

1.13 The current flowing into a box is given by the waveform shown in Fig. P1.13. Calculate the following quantities: (a) the amount of charge which has entered the box at $t = 1$ s, $t = 3$ s, and $t = 4.5$ s, (b) the power absorbed by the box at $t = 1$ s, 2.5 s, 4.5 s, and 5.5 s and (c) the amount of energy absorbed by the box between 0 and 6 s.

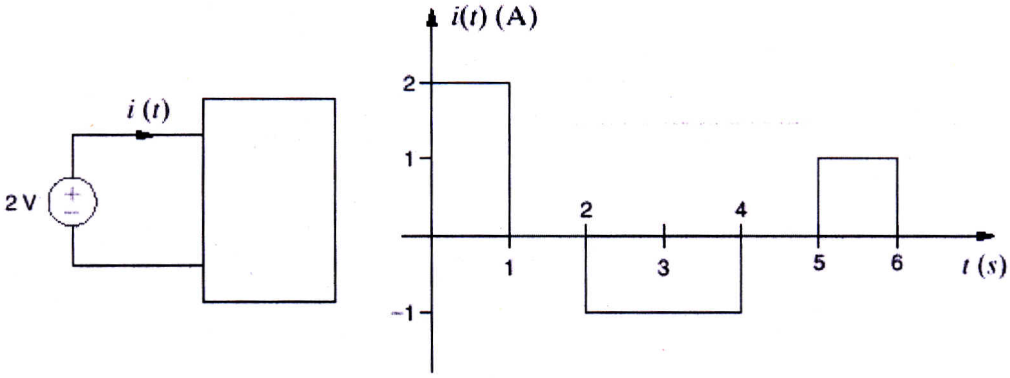


Figure P1.13.

SOLUTION:

a) $q(t) = \int_{-\infty}^{t} i(x)\,dx$

$q(t) = \int_0^t 2\,dx = 2t\Big]_0^1 = 2C$

$q(1) = 2C$

$q(t) = \int_0^1 2\,dx + \int_2^t -1\,dx$

$q(t) = 2 - x\Big]_2^t$

$q(t) = 2 + [-t + 2]$

$q(t) = -t + 4$

$q(3) = 1C$

By counting the areas:

$q(4.5) = 2(1) + 2(-1)$

$q(4.5) = 0C$

b) At $t = 1s$

$v(t).\,i(t) = 2*2 = 4W$

At $t = 2.5s$

$v(t).\,i(t) = 2*(-1) = -2W$ (power is given out by the box)

At $t = 4.5s$

$i(t) = 0 \Rightarrow$ Power $= 0W$

At $t = 5.5s$

$v(t).\,i(t) = 2*1 = 2W$

c) $W = \int_1 v(t)\,i(t)\,dt$

$$W = \int_0^1 2(2)\,dt + \int_2^4 2(-1)\,dt + \int_5^6 2(1)^2\,dt$$

$$W = 4t\Big]_0^1 - 2t\Big]_2^4 + 2t\Big]_5^6$$

$$W = 4 - 2[2] + 2[6-5]$$

$$W = 4 - 4 + 2 = 2J$$

1.14 The charge flowing into the box is shown in the graph in Fig. P1.14. Sketch the power absorbed by the box.

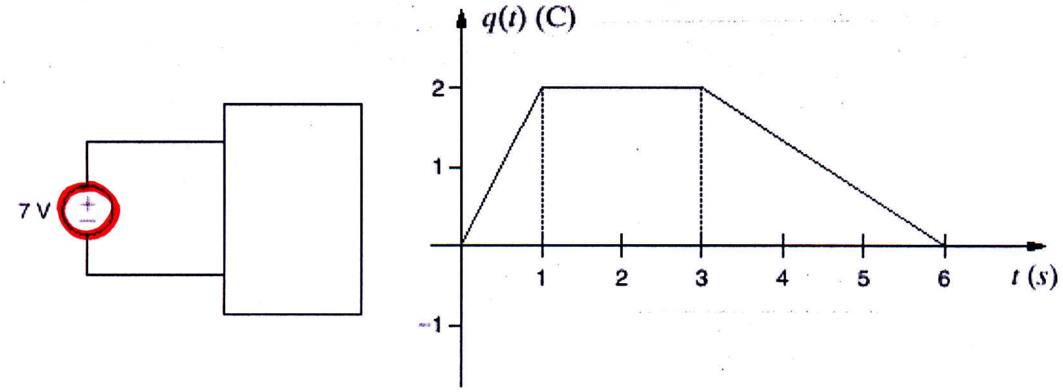


Figure P1.14

SOLUTION:

$$p(t) = V(t)\, i(t)$$

$$i(t) = \frac{dq(t)}{dt}$$

$$q(t) = m_1 t + b_1$$

$$m_1 = \frac{2-0}{1-0} = 2$$

$$q(t) = 2(t) + b_1$$

$$b_1 = 0$$

$$q(t) = 2t, \quad 0 \leq t \leq 1$$

$$q(t) = 2, \quad 1 \leq t \leq 3$$

$$q(t) = m_2 t + b_2$$

$$m_2 = \frac{0-2}{6-3} = -2/3$$

$$q(t) = -2/3\, t + b_2$$

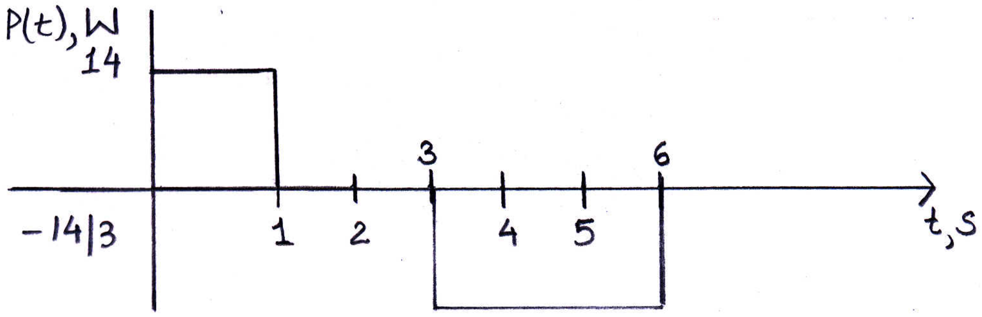
$$0 = -2/3(6) + b_2$$

$$b_2 = 4$$

$$q(t) = -2/3\, t + 4, \quad 3 \leq t \leq 6$$

$$i(t) = \begin{cases} 2A & 0 \leq t \leq 1 \\ 0A & 1 \leq t \leq 3 \\ -2/3A & 3 \leq t \leq 6 \end{cases}$$

$$p(t) = \begin{cases} 14\,W & , 0 \leq t \leq 1s \\ 0\,W & , 1 \leq t \leq 3s \\ -\frac{14}{3}\,W & , 3s \leq t \leq 6s \end{cases}$$



1.15 The charge that enters a BOX is shown in Fig. P1.15. Calculate and sketch the current flowing into and the power absorbed by the BOX between 0 and 9 milliseconds. Also calculate the energy absorbed by the BOX between 0 and 9 milliseconds.

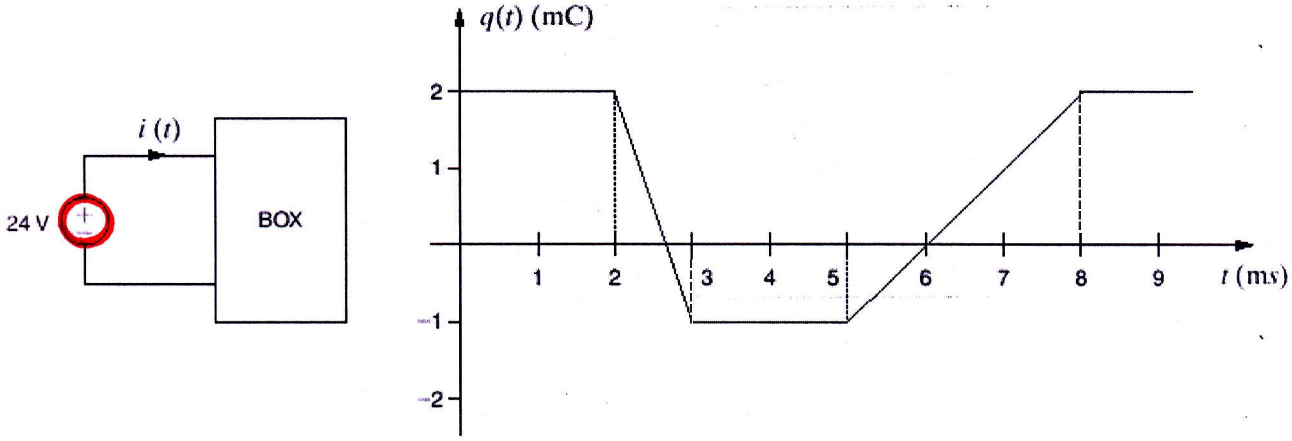


Figure P1.15

SOLUTION:

$$i(t) = \frac{dq(t)}{dt}$$

$$q(t) = 2, \quad 0 \leq t \leq 2ms$$

$$m = \frac{-1-2}{3-2} = \frac{-3}{1} = -3$$

$$q(t) = m(t) + b$$

$$q(t) = -3t + b$$

$$2 = -3(2) + b$$

$$b = 8$$

$$q(t) = -3t + 8, \quad 2ms \leq t \leq 3ms$$

$$q(t) = -1, \quad 3ms \leq t \; 5ms$$

$$q(t) = mt + b$$

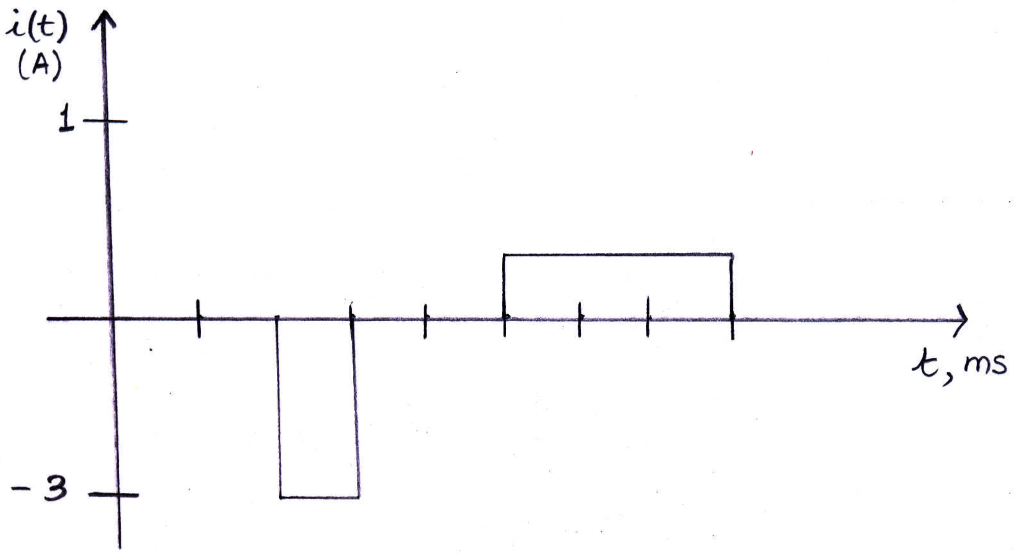
$$m = \frac{2+1}{8-5} = 1$$

$$q(t) = t + b$$

$$2 = 8 + b$$

$$b = -6$$

$$q(t) = t-6, \quad 5ms \leq t \leq 8ms$$
$$q(t) = 2, \quad 8ms \leq t \leq 9ms$$



$$i(t) = \begin{cases} 0, & 0 \leq t \leq 2ms \\ -3, & 2ms \leq t \leq 3ms \\ 0, & 3ms \leq t \leq 5ms \\ 1, & 5ms \leq t \leq 8ms \end{cases}$$

$$p(t) = v(t)\, i(t)$$

$$p(t) = \begin{cases} 0\ W, & 0 \leq t \leq 2ms \\ -72\ W, & 2ms \leq t \leq 3ms \\ 0\ W, & 3ms \leq t \leq 5ms \\ 24\ W, & 5ms \leq t \leq 8ms \end{cases}$$

$$W(t) = \int_0^9 p(t)\, dt$$

$$= 0 + (-72) \times 1 + 0 + 24 \times 3 = 0\,J$$

1.16 Determine the amount of power absorbed or supplied by the element in Fig. P1.16 if

(a) $V_1 = 5$ V and I = 6 A.

(b) $V_1 = 5$ V and I = -7 A.

(c) $V_1 = -14$ V and I = 6 A.

(d) $V_1 = -14$ V and I = -7 A.

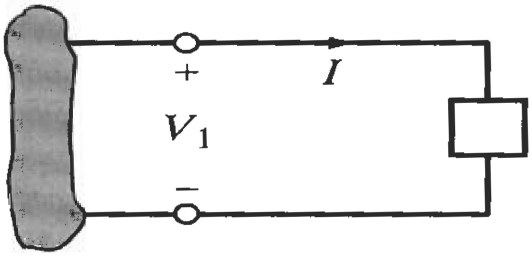
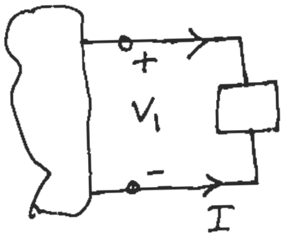


Figure P1.16

Solution:

1.16 a) $V_1 = 5V$, $I = 6A$



For passive sign convention,

$P = V_1 I$ is power absorbed.

$P = V_1 I = 5(6) = 30W$ absorbed

$\boxed{P = 30W \text{ absorbed}}$

b) $V_1 = 5V$, $I = -7A$

$P = 5(-7) = -35W$ $\boxed{P = 35 \text{ W supplied}}$

c) $V_1 = -14V$, $I = 6A$

$P = -84W$ $\boxed{P = 84 \text{ W supplied}}$

d) $V_1 = -14V$, $I = -7A$

$P = 98W$ $\boxed{P = 98 \text{ W absorbed}}$

1.17 Determine the missing quantity in the circuits in Fig. P1.17.

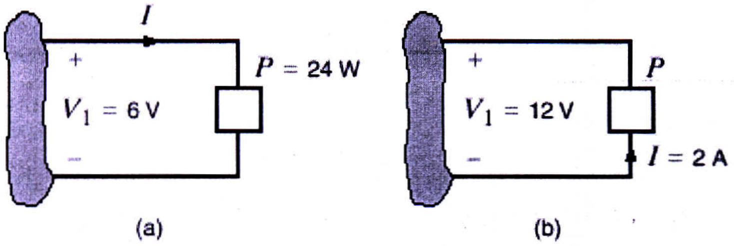


Figure P1.17

SOLUTION:

a) $I = \frac{P}{V} = \frac{24}{6} = 4A$

b) $P = VI = (-12)(2) = -24W$

$P = 24W$ supplied

1.18 Repeat Problem 1.17 for the circuits in Fig. P1.18.

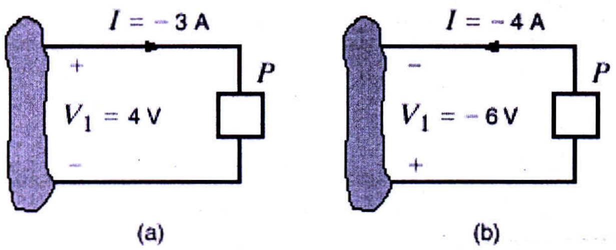


Figure P 1.18

SOLUTION:

a) $P = VI$

$P = 4(-3)$

$P = -12W$

$P = 12W$ supplied

b) $P = -6(-4)$

$P = 24W$ absorbed

1.19 Determine the power supplied to the elements in Fig. P1.19.

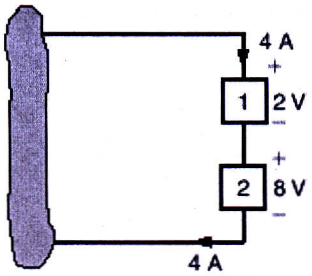


Figure P1.19

SOLUTION:

$$P_1 = V_1 I = 2(4) = 8W$$

$$P_2 = V_2 I = 8(4) = 32W$$

1.20 Determine the power supplied to the elements in Fig. P1.20.

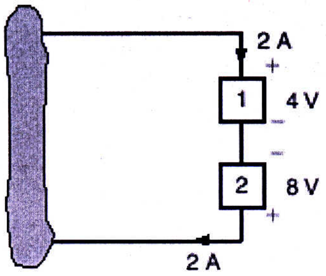


Figure P1.20

SOLUTION:

$P_1 = V_1 I = 4(2) = 8W$

$P_2 = V_2 I = (-8)(2)$

$P_2 = -16W$

1.21 **(a)** In Fig. P1.21 (a), $P_1 = 42$ W. How much power is element 2 absorbing?

(b) In Fig. P1.21 (b), $P_2 = -72$ W. How much power is element 1 absorbing?

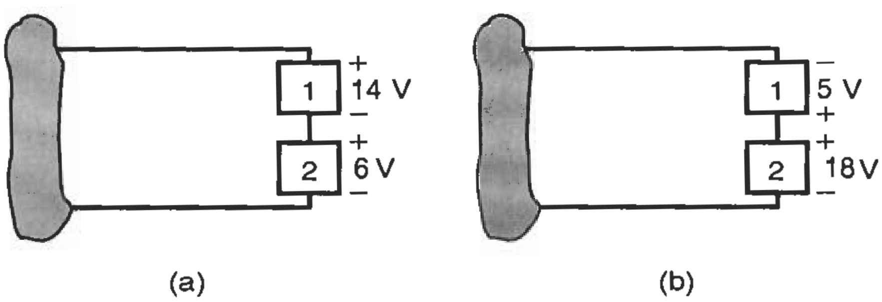
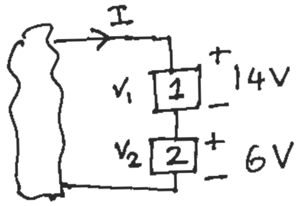


Figure P1.21

Solution:

1.21 a) $P_1 = 42$ W.



By default, using passive sign convention, since P_1 is positive, I flows as shown in the circuit diagram.

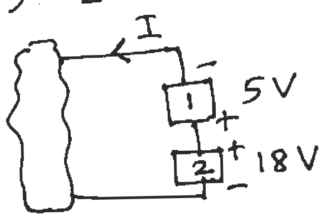
$P_1 = V_1 I \qquad I = P_1/V_1 = 42/14 = 3A$

$I = 3A$

For element 2, V_2 and I are defined in passive sign convention: $P_2 = V_2 I = 6(3) = 18$ W

$\boxed{P_2 = 18\text{W absorbed}}$

b) $P_2 = -72$ W.



Again passive sign convention is the default. Since $P_2 < 0$, element 2 supplies power and I flows as shown.

$P_2 = -V_2 I = -18 I \qquad I = \frac{-72}{-18} = 4A$

For element 1, V_1 and I are defined in passive sign convention. Power absorbed is $P_1 = V_1 I = 5(4) = 20$W

$\boxed{P_1 = 20\text{W absorbed}}$

1.22 Two elements are connected in series, as shown in Fig. P 1.22 Element 1 supplies 24 W of power. Is element 2 absorbing or supplying power, and how much?

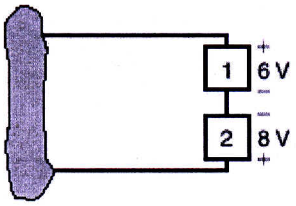


Figure P 1.22

SOLUTION:

$P_1 = 24\,W$

$I = \frac{P_1}{V_1}$

$I = \frac{24}{6}$

$I = 4A$

$P_2 = V_2 I$

$P_2 = 8(4)$

$P_2 = 32\,W$ absorbed

1.23 Two elements are connected in series, as shown in Fig. P1.23. Element 1 supplies 24 W of power. Is element 2 absorbing or supplying power, and how much?

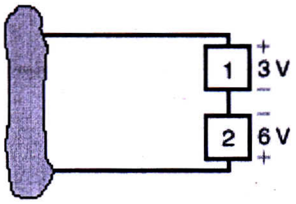


Figure P 1.23

SOLUTION:

$P_1 = 24\,W$

$I = \frac{P_1}{V_1} = \frac{24}{3}$

$I = 8A$

$P_2 = V_2 I = 6(8)$

$P_2 = 48$ absorbed

1.24 Two elements are connected in series, as shown in Fig. P 1.24. Element 1 absorbs 45 W of power. Is element 2 absorbing or supplying power, and how much?

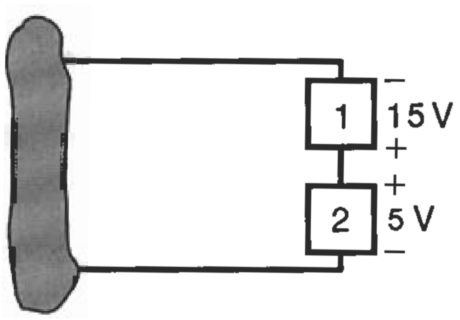
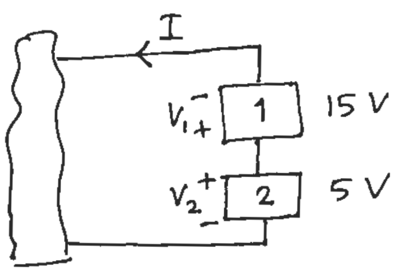


Figure P1.24

Solution:

1.24 Element 1 absorbs 45 W. For absorbing power, I must flow as shown in the diagram.



$$P_1 = V_1 I, \quad I = \frac{P_1}{V_1} = \frac{45}{15} = 3\text{A}$$

$$I = 3\text{A}$$

For element 2, V_2 and I are defined in active sign convention. Power supplied is

$$P_2 = V_2 I = 5(3) = 15\text{W}$$

$$\boxed{P_2 = 15 \text{ W supplied}}$$

1.25 Choose I_s such that the power absorbed by element 2 in Fig. P 1.25 is 7 W.

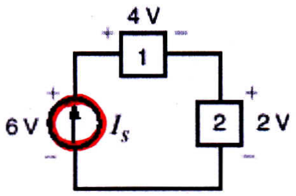


Figure P 1.25

SOLUTION:

$P_2 = 7W$ absorbed

$P_2 = V_2 I_S$

$I_S = \dfrac{P_2}{V_2} = \dfrac{7}{2}$

$I_S = 3.5A$

1.26 Determine the power that is absorbed or supplied by the circuit elements in Fig. P 1.26.

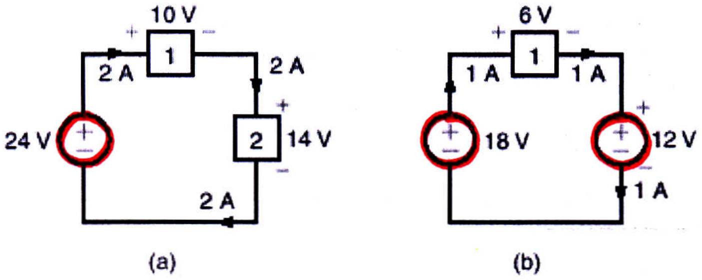


Figure P 1.26

SOLUTION:

a) $P_{24V} = (-24)(2) = -48W$

$P_{24W} = 48W$ supplied

$P_1 = 10(2) = 20W$ absorbed

$P_2 = 14(2) = 28W$ absorbed

b) $P_{18V} = (-18)(1) = -18W$

$P_{18V} = 18W$ supplied

$P_1 = 6(1) = 6W$ absorbed

$P_{12V} = 12(1) = 12W$ absorbed

1.27 Find the power that is absorbed or supplied by the circuit elements in Fig. P1.27.

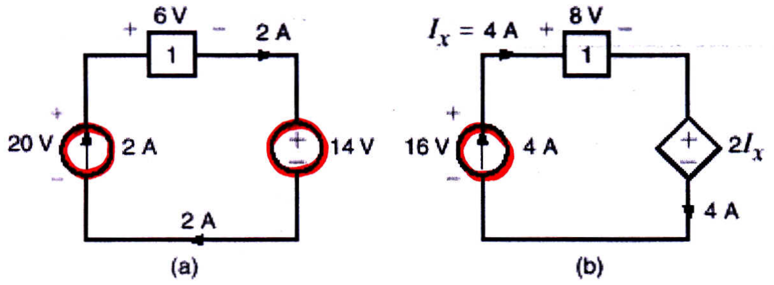


Figure P1.27

SOLUTION:

a) $P_{2A} = -20(2)$

$P_{2A} = -40W$

$P_{2A} =$ 40 W supplied

$P_1 = 6(2) = 12W$ absorbed

$P_{14V} = 14(2) = 28W$ absorbed

b) $P_{4A} = 16(-4) = -64W$

$P_{4A} =$ 64 W supplied

$P_1 = 8(4) = 32W$ absorbed

$P_{2I_X} = (2I_X)(4) = 2(4)(4)$

$P_{2I_X} =$ 32 W absorbed

1.28 Determine the power that is absorbed or supplied by the circuit elements in Fig. P1.28.

(a) Power of element 1 at figure (a).
(b) Power of element 2 at figure (a).
(c) Power of element 3 at figure (a).
(d) Power of element 1 at figure (b).
(e) Power of element 2 at figure (b).
(f) Power of element 3 at figure (b).
(g) Power of element 4 at figure (b).

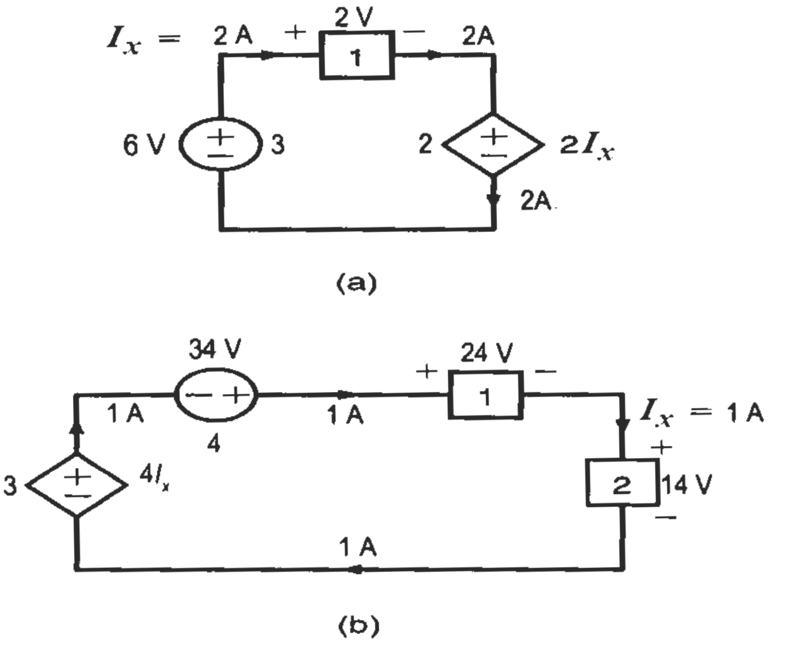


Figure P1.28

Solution: See next page.

1.28 a) Voltage and current for element 1 in Fig. (a) are defined in the passive sign convention.

Power supplied by element 1 in fig. (a) is

$$P_1 = -V_1 I_X = -2(2) = -4\,W$$

$\boxed{P_1 = -4\,W \text{ supplied.}}$

b) Voltage and current for element 2 in fig. (a) are defined in the passive sign convention.

Power supplied by element 2 in fig. (a) is

$$P_2 = -(2I_x) = -4(2) = -8\,W$$

$\boxed{P_2 = -8\,W \text{ supplied}}$

c) For element 3 in fig. (a) V and I are defined in active sign convention.

Power supplied by element 3 in fig. (a) is

$$P_3 = 6\,I_X = 6(2) = 12\,W$$

$\boxed{P_3 = 12\,W \text{ supplied}}$

d) V and I are defined in the passive sign convention for element 1 in Fig. (b).

Power supplied by element 1 in fig. (b) is

$$P_1 = -V_1 I_X = -24(1) = -24\,W$$

$\boxed{P_1 = -24\,W \text{ supplied}}$

e) V and I are defined in the passive sign convention for element 2 in Fig. (b).

Power supplied by element 2 in Fig. (b) is

$$P_2 = -V_2 I_x = -14(1) = -14W$$

$$\boxed{P_2 = -14W \text{ supplied}}$$

f) V and I are defined in the active sign convention for element 3 in Fig. (b).

Power supplied by element 3 in Fig. (b) is

$$P_3 = (4 I_x) I_x = 4 W$$

$$\boxed{P_3 = 4W \text{ supplied}}$$

g) V and I are defined in the active sign convention for element 4 in Fig. (b).

Power supplied by element 4 in Fig. (b) is

$$P_4 = 34(I_x) = 34W \text{ supplied}$$

$$\boxed{P_4 = 34 W \text{ supplied}}$$

1.29 Compute the power that is absorbed or supplied by the elements in the network in Fig. P1.29.

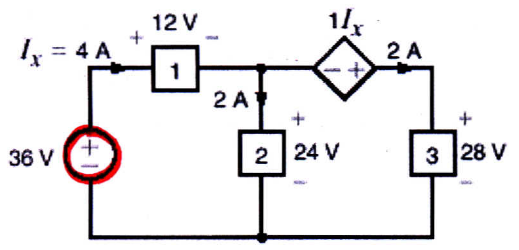


Figure P 1.29

SOLUTION:

$$P_{36V} = -36(4) = -144\,W$$

P_{36V} = 144 W supplied

P_1 = 12(4) = 48 W absorbed

P_2 = 24(2) = 48 W absorbed

$$P_{1I_x} = (-I_x)(2) = -4(2) = -8\,W$$

P_{1I_x} = 8 W supplied

P_3 = 28(2) = 56 W absorbed

1.30 Calculate the power absorbed by each element in the circuit in Fig. P1.30.

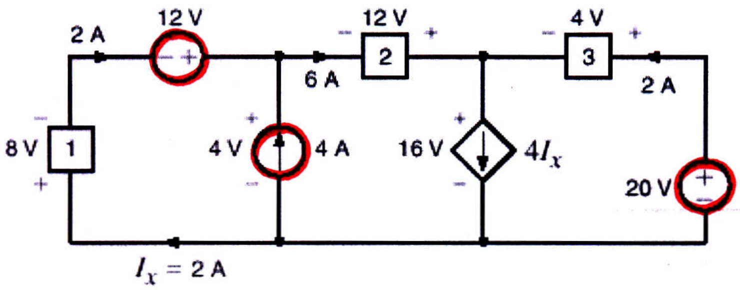


Figure P 1.30

SOLUTION:

$P_{12V} = -12(2) = -24\text{ W}$

$P_{12V} = 24\text{ W}$ supplied

$P_{4A} = 4(-4) = -16\text{ W}$

$P_{4A} = 16\text{ W}$ supplied

$P_2 = -12(6) = -72\text{ W}$

$P_2 = 72\text{ W}$ supplied

$P_3 = 4(2) = 8\text{ W}$ absorbed

$P_{20V} = -20(2) = -40\text{ W}$

$P_{20V} = 40\text{ W}$ supplied

$P_1 = 8(2) = 16\text{ W}$ absorbed

KCL: $6 + 2 = 4I_x$

$I_x = 2\text{A}$

$P_{4I_x} = 4I_x(16)$

$P_{4I_x} = 4(2)(16)$

$P_{4I_x} = 128\text{ W}$ absorbed

1.31 Find V_x in the network in Fig. P 1.31 using Tellegen's theorem.

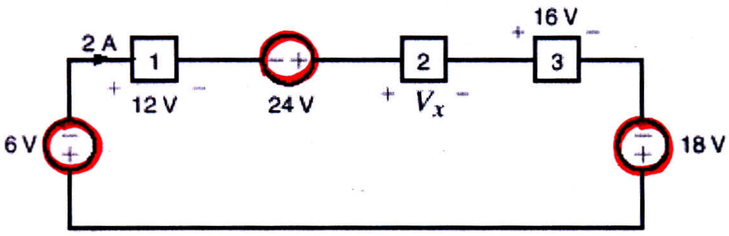


Figure P 1.31

SOLUTION:

$P_1 = 12(2) = 24W$ absorbed

$P_2 = V_x(2) = 2V_x$ absorbed

$P_3 = 16(2) = 32W$ absorbed

$P_{6V} = 6(2) = 12W$ absorbed

$P_{24V} = 24(-2) = -48W$

$P_{24V} = 48W$ supplied

Power supplied = Power absorbed

$P_{24V} + P_{18V} = P_1 + P_2 + P_3$

$48 + 36 = 24 + 2V_x + 32$

$V_x = 8V$

1.32 Find V_x in the network in Fig. P1.32.

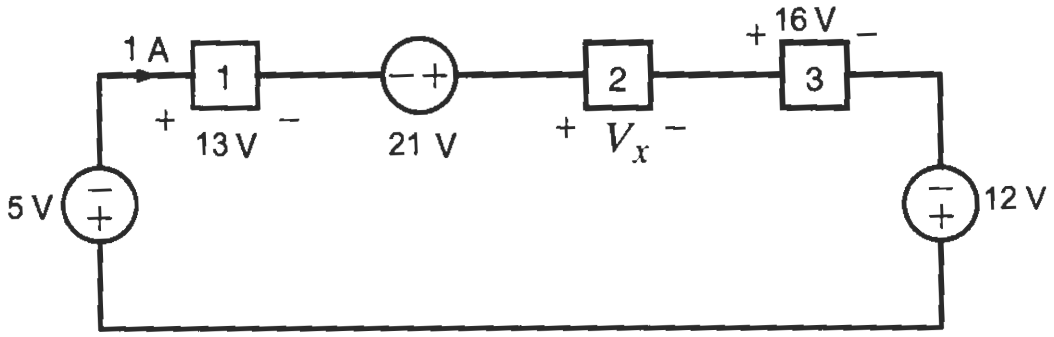


Figure P1.32

Solution:

1.32 Passive sign convention: Elements 1, 2, 3 and the 5V source.

Active sign convention: 21V and 12V source.

Power balance: $P_{21V} + P_{12V} = P_1 + P_2 + P_3 + P_{5V}$

$$21I + 12I = 13I + V_x I + 16I + 5I$$

$$33 = 34 + V_x$$

$$\boxed{V_x = -1V}$$

1.33 Find V_x in the network in Fig. P1.33 using Tellegen's theorem.

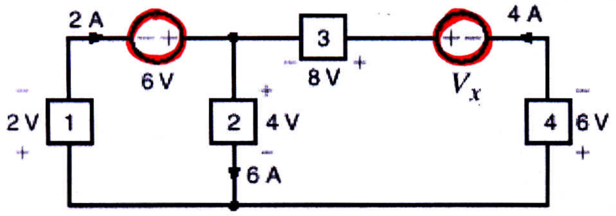


Figure P1.33

SOLUTION:

Power supplied = Power absorbed

$$P_{6V} + P_{Vx} = P_1 + P_2 + P_3 + P_4$$

$P_1 = 2(2) = 4$ W absorbed

$P_2 = 4(6) = 24$W absorbed

$P_3 = 8(4) = 32$W absorbed

$P_4 = 6(4) = 24$W absorbed

$P_{6V} = 6(-2) = -12$W

$P_{6V} = 12$W supplied

$$P_{6V} + P_{Vx} = P_1 + P_2 + P_3 + P_4$$

$$12 + P_{Vx} = 4 + 24 + 32 + 24$$

$P_{Vx} = -4V_x$

$P_{Vx} = 4V_x$ supplied

$$12 + 4V_x = 4 + 24 + 32 + 24$$

$$V_x = 18\text{V}$$

1.34 Find I_x in the circuit in Fig. P1.34.

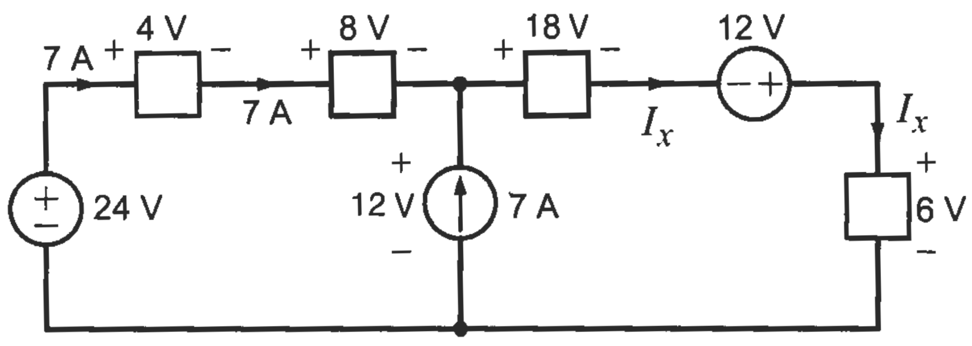
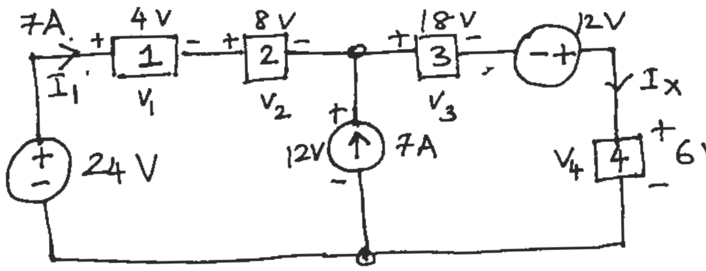


Figure P1.34

Solution:

1.34



Passive sign convention: elements 1, 2, 3, 4

$P_1 = V_1 I_1 = 4(7) = 28 \text{ W absorbed}$

$P_2 = V_2 I_1 = 8(7) = 56 \text{ W absorbed}$

$P_3 = V_3 I_x = 18 I_x \text{ absorbed}$

$P_4 = V_4 I_x = 6 I_x \text{ absorbed}$

$P_{24V} = 24 I_1 = 168 \text{ W supplied}$

$P_{7A} = 12(7) = 84 \text{ W supplied}$

$P_{12V} = 12 I_x \text{ supplied}$

Power supplied = Power absorbed

$P_{24V} + P_{7A} + P_{12V} = P_1 + P_2 + P_3 + P_4$

$12 I_x = 168 \quad \boxed{I_x = 14 \text{ A}}$

1.35 Is the source V_s in the network in Fig. P1.35 absorbing or supplying power, and how much?

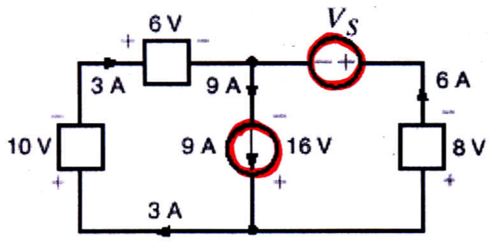


Figure P 1.35

SOLUTION:

$P_{10V} = 10(3) = 30W$ absorbed

$P_{6V} = 6(3) = 18W$ absorbed

$P_{9A} = 16(-9) = -144W$

$P_{9A} = 144W$ supplied

$P_{V_S} = V_S(6) = 6V_S$ absorbed

$P_{8V} = 8(6) = 48W$ absorbed

Power supplied = Power absorbed

$P_{9A} = P_{10V} + P_{6V} + P_{V_S} + P_{8V}$

$144 = 30 + 18 + 6V_S + 48$

$144 = 96 + 6V_S$

$24 = 16 + V_S$

$V_S = 8V$

$P_{V_S} = 8(6) = 48W$ absorbed

1.36 Find V_x in the network in Fig. P1.36 using Tellegen's theorem.

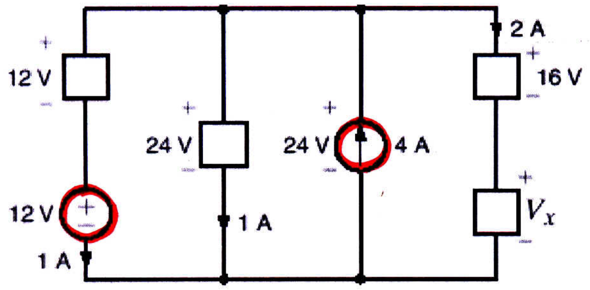


Figure P1.36

SOLUTION:

$P_1 = 12(1) = 12W$ absorbed

$P_{12V} = 12(1) = 12W$ absorbed

$P_2 = 24(1) = 24W$ absorbed

$P_{4A} = 24(-4) = -96W$

$P_{4A} = 96W$ supplied

$P_3 = 16(2) = 32W$ absorbed

$P_4 = V_x(2) = 2V_x$

Power supplied = Power absorbed

$$P_{4A} = P_1 + P_{12V} + P_2 + P_3 + P_4$$

$$96 = 12 + 12 + 24 + 32 + 2V_x$$

$$V_x = 8V$$

1.37 Find I_o in the network in Fig. P1.37 using Tellegen's theorem.

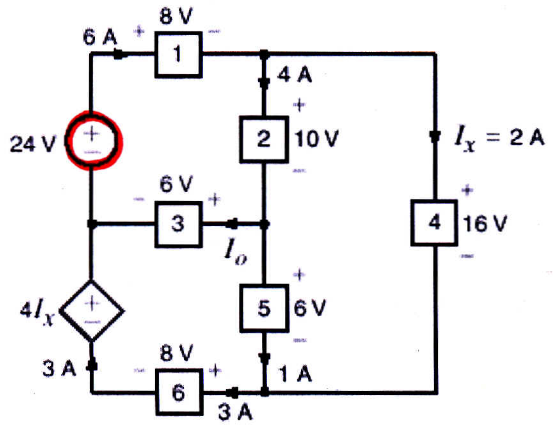


Figure P 1.37

SOLUTION:

$P_{24V} = 24(-6) = -144\,W$

$P_{24V} = 144\,W$ supplied

$P_1 = 8(6) = 48\,W$ absorbed

$P_2 = 10(4) = 40\,W$ absorbed

$P_3 = 6I_0$ ABSORBED

$P_4 = 16(2) = 32\,W$ absorbed

$P_5 = 6(1) = 6\,W$ absorbed

$P_6 = 8(3) = 24\,W$ absorbed

$P_{4I_x} = 4I_x(-3) = -12(2) = -24\,W$

$P_{4I_x} = 24\,W$ supplied

Power supplied = Power absorbed

$P_{24V} + P_{4I_x} = P_1 + P_2 + P_3 + P_4 + P_5 + P_6$

$144 + 24 = 48 + 40 + 6I_0 + 32 + 6 + 24$

$I_0 = 3A$

1.38 Find V_x in the network in Fig. P1.38.

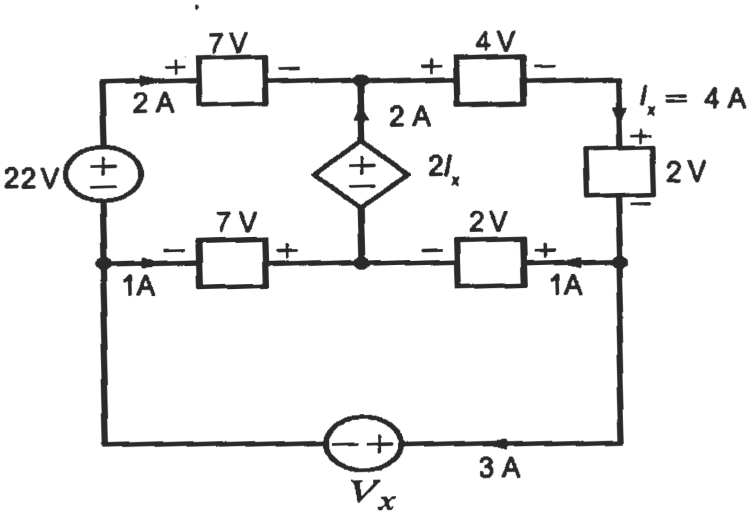
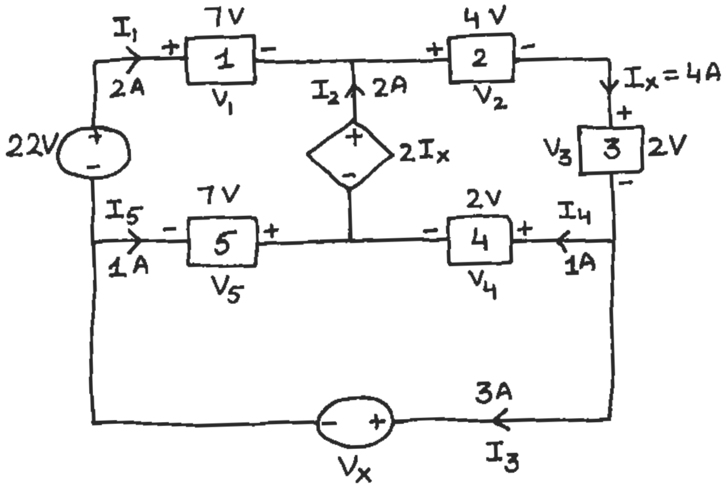


Figure P 1.38

Solution: 1·38

Passive sign convention elements 1, 2, 3, 4, V_x



$P_1 = V_1 I_1 = 7(2) = 14\text{ W absorbed}$

$P_2 = V_2 I_x = 4(4) = 16\text{ W absorbed}$

$P_3 = V_3 I_x = 2(4) = 8\text{ W absorbed}$

$P_4 = V_4 I_4 = 2(1) = 2\text{ W absorbed}$

$P_{V_x} = V_x I_3 = 3V_x\text{ absorbed}$

$P_{22V} = 22\, I_1 = 22(2)$

$= 44\text{ W supplied}$

$P_5 = V_5 I_5 = 7\text{ W supplied}$

$P_{2I_x} = 2 I_x I_2 = 16\text{ W supplied}$

$$P_{supplied} = P_{absorbed}$$

$$P_{22V} + P_5 + P_{2I_x} = P_1 + P_2 + P_3 + P_4 + P_{V_x}$$

$$44 + 7 + 16 = 14 + 16 + 8 + 2 + 3V_x$$

$$27 = 3V_x \Rightarrow \boxed{V_x = 9V}$$

2.1 Determine the current and power dissipated in the resistors in Fig. P2.1.

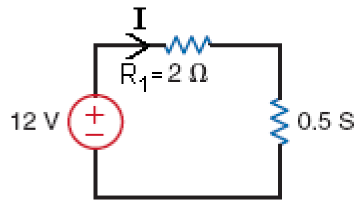


Figure P2.1

SOLUTION:

$R_2 = \frac{1}{0.5} = 2\Omega$

$I = \frac{12}{2+2}$

$I = 3A$

$P_{R_1} = I^2 R_1 = (3)^2(2)$

$P_{R_1} = 18\,W$

$P_{R_2} = I^2 R_2 = (3)^2(2)$

$P_{R_2} = 18\,W$

2.2 Determine the voltage across the resistor in Fig. P2.2 and the power dissipated.

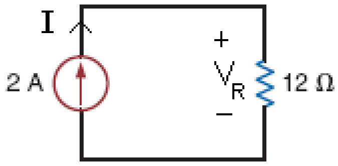


Figure P2.2

SOLUTION:

$$V_R = IR$$

$$V_R = 2(12) = 24\text{ V}$$

$$P_R = I^2R = 2^2(12)$$

$$P_R = 48\text{ W}$$

2.3 Given the circuit in Fig. P2.3, find the voltage across each resistor and the power dissipated in each.

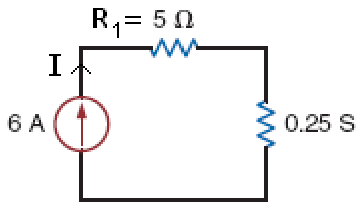


Figure P2.3

SOLUTION:

$$R_2 = \frac{1}{0.25} = 4\,\Omega$$

$$V_{R1} = IR_1$$

$$V_{R1} = 6(5) = 30\text{V}$$

$$V_{R2} = IR_2 = 6(4) = 24\text{ V}$$

$$P_{R1} = \frac{V_{R1}^2}{R_1} = \frac{(30)^2}{5}$$

$$P_{R1} = 180\text{W}$$

$$P_{R2} = \frac{V_{R2}^2}{R_2} = \frac{(24)^2}{4}$$

$$P_{R2} = 144\text{ W}$$

2.4 In the network in Fig. P2.4, the power absorbed by R_x is 20 mW. Find R_x.

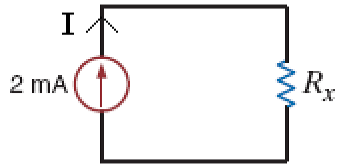


Figure P2.4

SOLUTION:

$$P_{Rx} = 20\text{mW}$$

$$P_{Rx} = I^2 R_x$$

$$R_x = \frac{P_{Rx}}{I^2} = \frac{20\text{m}}{(2\text{m})^2} = \frac{20\times10^{-3}}{(2\times10^{-3})^2} = \frac{20\times10^{-3}}{4\times10^{-6}}$$

$$R_x = 5\text{K}\Omega$$

2.5 In the network in the accompanying Figure, the power absorbed by G_x is 60 mW, Find G_x.

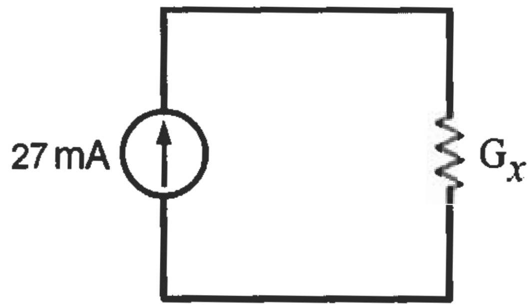


Figure P2.5

Solution: 2·5

$$P_G = 60\ mW \quad ; \quad I = 27 \times 10^{-3}\ A$$

$$P_G = R_x I^2$$

$$60 \times 10^{-3} = \frac{1}{G_x} I^2 \qquad \left(\because R_x = \frac{1}{G_x} \right)$$

$$\Rightarrow G_x = \frac{(27 \times 10^{-3})^2}{60 \times 10^{-3}}$$

$$\boxed{G_x = 12.15\ mS}$$

2.6 A model for a standard two D-cell flashlight is shown in Fig. P2.6. Find the power dissipated in the lamp.

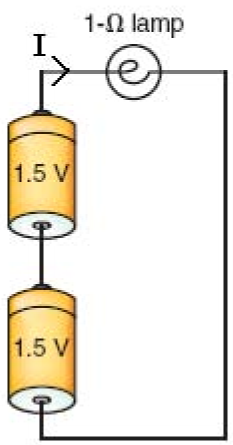


Figure P2.6

SOLUTION:

$$I = \frac{V}{R}$$

$$I = \frac{1.5 + 1.5}{1}$$

$$I = 3A$$

$$P_{lamp} = I^2R = 3^2(1)$$

$$P_{lamp} = 9W$$

2.7 An automobile uses two halogen headlights connected as shown in Fig. P2.7. Determine the power supplied by the battery if each headlight draws 3 A of current.

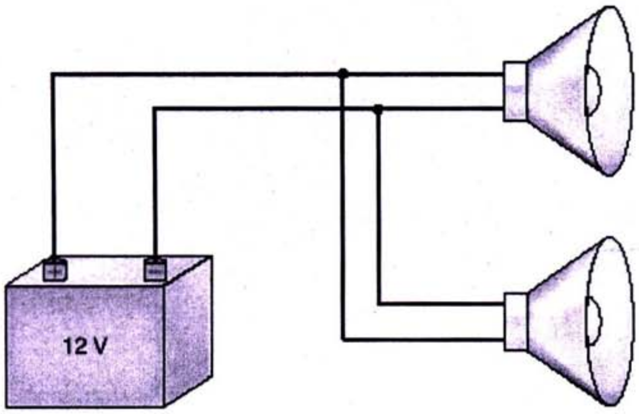


Figure P2.7

SOLUTION:

$$I_1 = I_2 = 3A$$

$$I = I_1 + I_2 = 6A$$

$$P_{12V} = VI = 12(6)$$

$$P_{12V} = 72 \text{ W}$$

2.8 Many years ago a string of Christmas tree lights was manufactured in the form shown in Fig. P2.8a. Today the lights are manufactured as shown in Fig. P2.8b. Is there a good reason for this change?

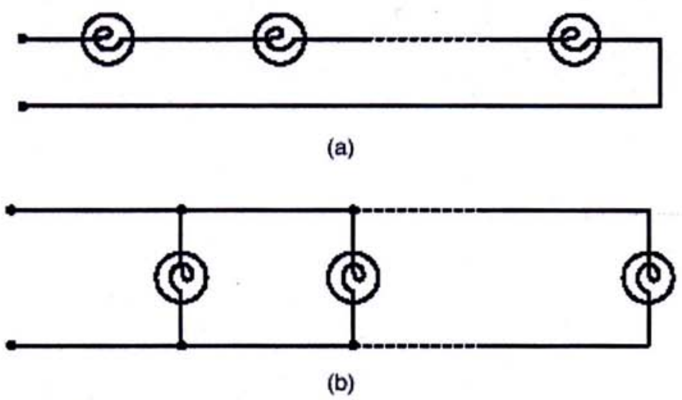


Figure P2.8

SOLUTION:

When Christmas tree lights are connected in series as shown in Figure 2.8a, an open circuit bulb failure will cause all bulbs to turn off (no current flows.)

If the bulbs are connected in parallel as shown in Figure 2.8b, an open circuit bulb failure will only cause one bulb to turn off. The other bulbs will still function when connected in parallel.

2.9 Find I_1 in the network in Fig. P2.9.

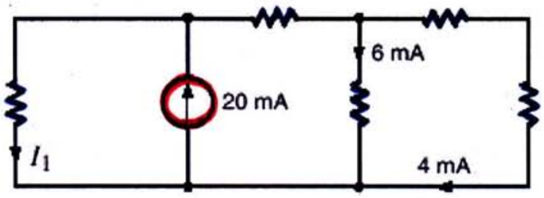


Figure P2.9

SOLUTION:

KCL at node B: $I_2 = 6m + 4m$

$I_2 = 10mA$

KCL at node A: $I_1 + I_2 = 20m$

$I_1 = 20m - 10m$

$I_1 = 10mA$

2.10 Find I_1 in the network in Fig. P2.10

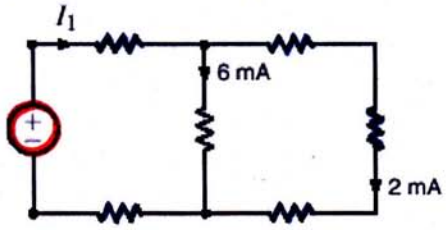


Figure P2.10

SOLUTION:

KCL at node A: $I_1 = 6m + 2m$

$I_1 = 8mA$

2.11 Find I_1 and I_2 in the circuit in Fig. P2.11.

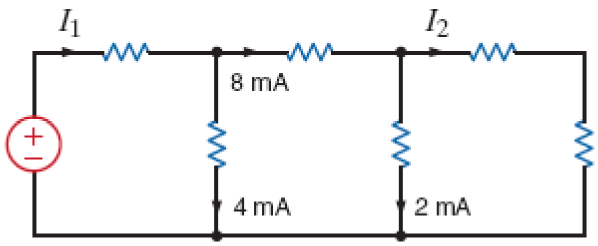
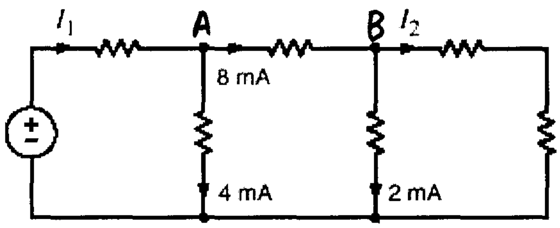


Figure P2.11

SOLUTION:



KCL at node A: $I_1 = 4m + 8m$

$I_1 = 12mA$

KCL at node B: $8m = 2m + I_2$

$I_2 = 6mA$

2.12 Find I_1 in the circuit in Fig. P2.12.

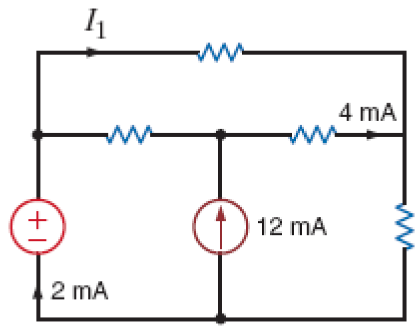
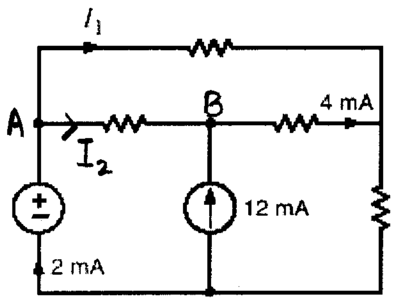


Figure P2.12

SOLUTION:



KCL at node B : $I_2 + 12m = 4m$

$I_2 = -8mA$

KCL at node A : $2m = I_1 + I_2$

$I_1 = 10mA$

2.13 Find I_x in the circuit in Fig. P2.13.

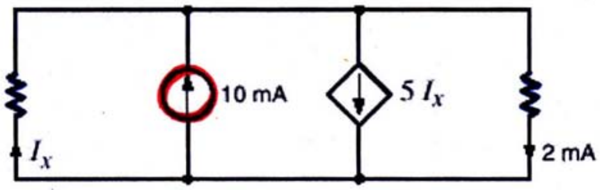


Figure P2.13

SOLUTION:

KCL: $I_x + 10m = 5I_x + 2m$

$4I_x = 8m$

$I_x = 2mA$

2.14 Determine I_L in the circuit in Fig. P2.14.

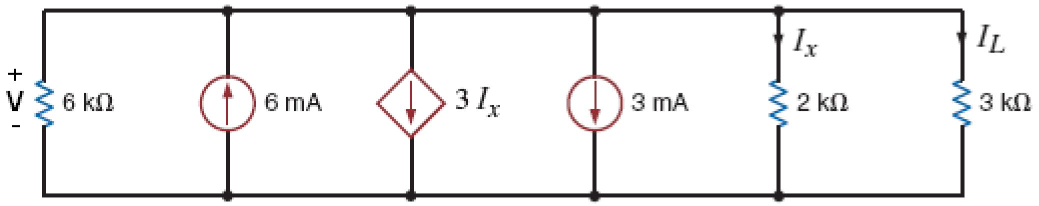


Figure P2.14

SOLUTION:

$$6m = \frac{V}{6K} + 3I_x + 3m + I_x + I_L$$

$$\frac{V}{6K} + 4I_x + I_L = 3m$$

$$I_x = \frac{V}{2K} \quad \text{and} \quad I_L = \frac{V}{3K}$$

$$\frac{V}{6K} + 4\left(\frac{V}{2K}\right) + \frac{V}{3K} = 3m$$

$$V + 12V + 2V = 18$$

$$15V = 18$$

$$V = \frac{18}{15}\ V$$

$$I_L = \frac{18}{15(3K)}$$

$$I_L = 0.4mA$$

2.15 Find **(a)** I_o and **(b)** I_1 in the circuit in the Figure.

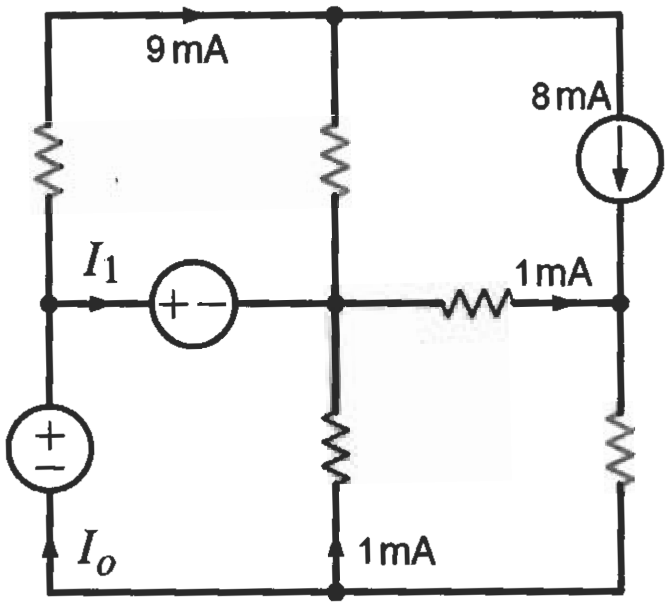
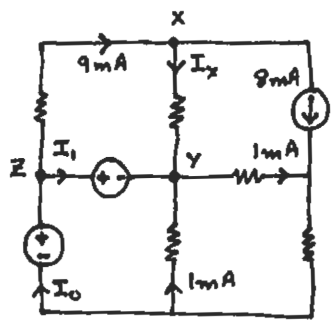


Figure P2.15

Solution: 2.15



KCL : Currents enter + Currents exit = 0

KCL at X :

$$9 \times 10^{-3} - 8 \times 10^{-3} - I_x = 0$$

$$\Rightarrow \quad I_x = 1\,mA$$

KCL at Y :

$$I_1 + I_x + 1 \times 10^{-3} - 1 \times 10^{-3} = 0$$

$$\Rightarrow \quad \boxed{I_1 = -1\,mA}$$

KCL at Z :

$$I_o - I_1 - 9 \times 10^{-3} = 0$$

$$\Rightarrow \quad \boxed{I_o = 8\,mA}$$

2.16 Find I_x, I_y, and I_z in the network in Fig. P2.16.

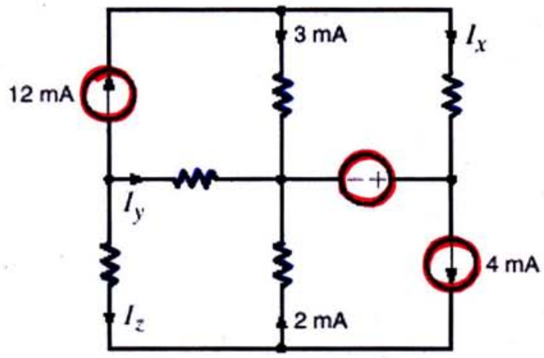


Figure P2.16

SOLUTION:

KCL at A: $12m = 3m + I_x$

$I_x = 9mA$

KCL at B: $I_z + 4m = 2m$

$I_z = -2mA$

KCL at C: $12m + I_y + I_z = 0$

$I_y = 2m - 12m$

$I_y = -10mA$

2.17 Find V_{bd} in the circuit in Fig. P2.17.

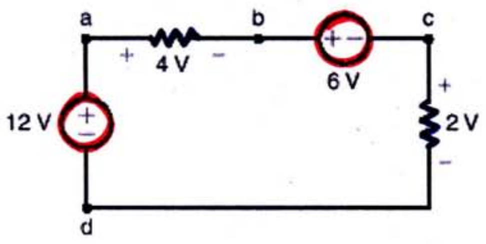


Figure P2.17

SOLUTION:

$$V_{bd} = V_{bc} + V_{cd}$$

$$V_{bd} = 6 + 2 = 8\text{V}$$

2.18 Find V_{ad} in the network in Fig. P2.18.

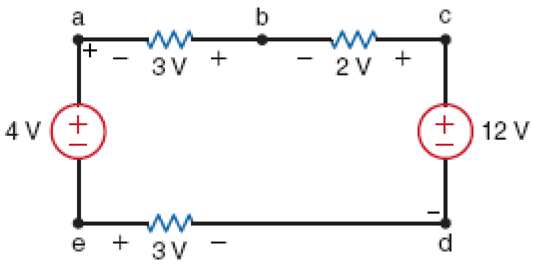


Figure P2.18

SOLUTION:

$$V_{ad} + 3 + 2 = 12$$

$$V_{ad} = 7V$$

2.19 Find V_{fb} and V_{ec} in the circuit in Fig. P2.19.

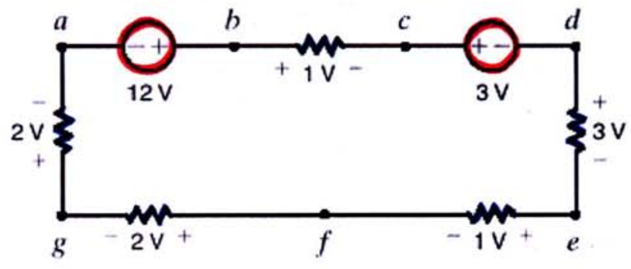


Figure P2.19

SOLUTION:

KVL around fbcdef :

$$V_{fb} + 1 + 3 + 3 + 1 = 0$$

$$V_{fb} = -8V$$

KVL around ecde :

$$V_{ec} + 3 + 3 = 0$$

$$V_{ec} = -6V$$

2.20 Find V_{ae} and V_{cf} in the circuit in Fig. P2.20.

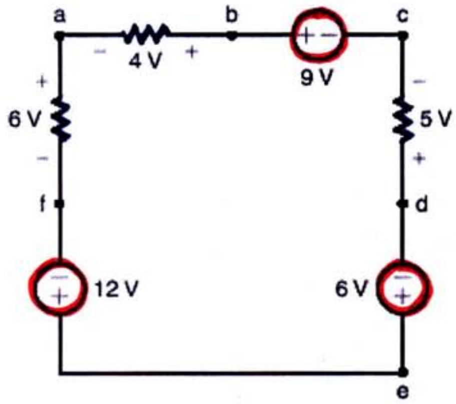


Figure P2.20

SOLUTION:

KVL around aefa :

$V_{ae} + 12 = 6$

$V_{ae} = -6V$

KVL around cfedc :

$V_{cf} + 5 + 6 = 12$

$V_{cf} = 1V$

2.21 Given the circuit diagram in Fig. P2.21, find the following voltages: V_{da}, V_{bh}, V_{gc}, V_{di}, V_{fa}, V_{ac}, V_{ai}, V_{hf}, V_{fb}, and V_{dc}.

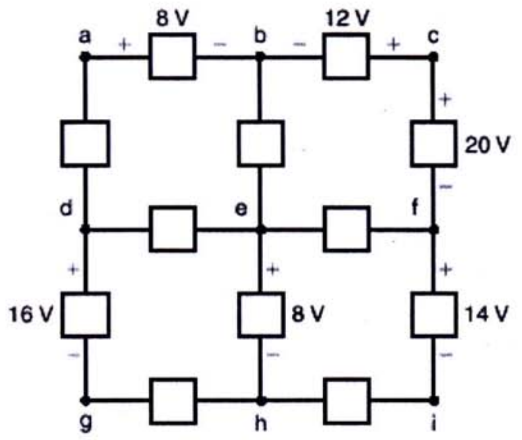


Figure P2.21

SOLUTION:

KVL : $V_{eh} = V_{ef} + V_{fi} + V_{ih}$

$V_{ef} = 8 - 14 - 4$

$V_{ef} = -10V$

KVL : $V_{de} + V_{ef} + V_{fi} + V_{ih} = V_{dg} + V_{gh}$

$V_{de} = 16 + 12 - (-10) - 14 - 4$

$V_{de} = 20V$

KVL : $V_{ef} + V_{be} + V_{cb} = V_{cf}$

$V_{be} = 20 - (-10) - 12$

$V_{be} = 18V$

KVL : $V_{de} = V_{da} + V_{ab} + V_{be}$

$V_{da} = 20 - 8 - 18$

$\boxed{V_{da} = -6V}$

$V_{bh} = V_{be} + V_{eh} = 18 + 8$

$\boxed{V_{bh} = 26V}$

KVL : $V_{gh} = V_{gc} + V_{in} + V_{fi} + V_{cf}$

$V_{gc} = 12 - 4 - 14 - 20$

$\boxed{V_{gc} = -26\text{V}}$

KVL : $V_{di} + V_{in} = V_{dg} + V_{gh}$

$V_{di} = -4 + 16 + 12$

$\boxed{V_{di} = 24\text{V}}$

KVL : $V_{fa} + V_{ab} + V_{cf} = V_{cb}$

$V_{fa} = 12 - 8 - 20$

$\boxed{V_{fa} = -16\text{V}}$

KVL : $V_{ac} + V_{cb} = V_{ab}$

$V_{ac} = 8 - 12$

$V_{ac} = -4\text{V}$

KVL : $V_{cf} + V_{fi} + V_{ia} + V_{ab} = V_{cb}$

$V_{ia} = 12 - 14 - 8 - 20$

$V_{ia} = -30\text{V}$

KVL : $V_{hf} + V_{fi} + V_{in} = 0$

$V_{hf} = -14 - 4$

$\boxed{V_{hf} = -18\text{V}}$

KVL : $V_{fb} + V_{cf} = V_{cb}$

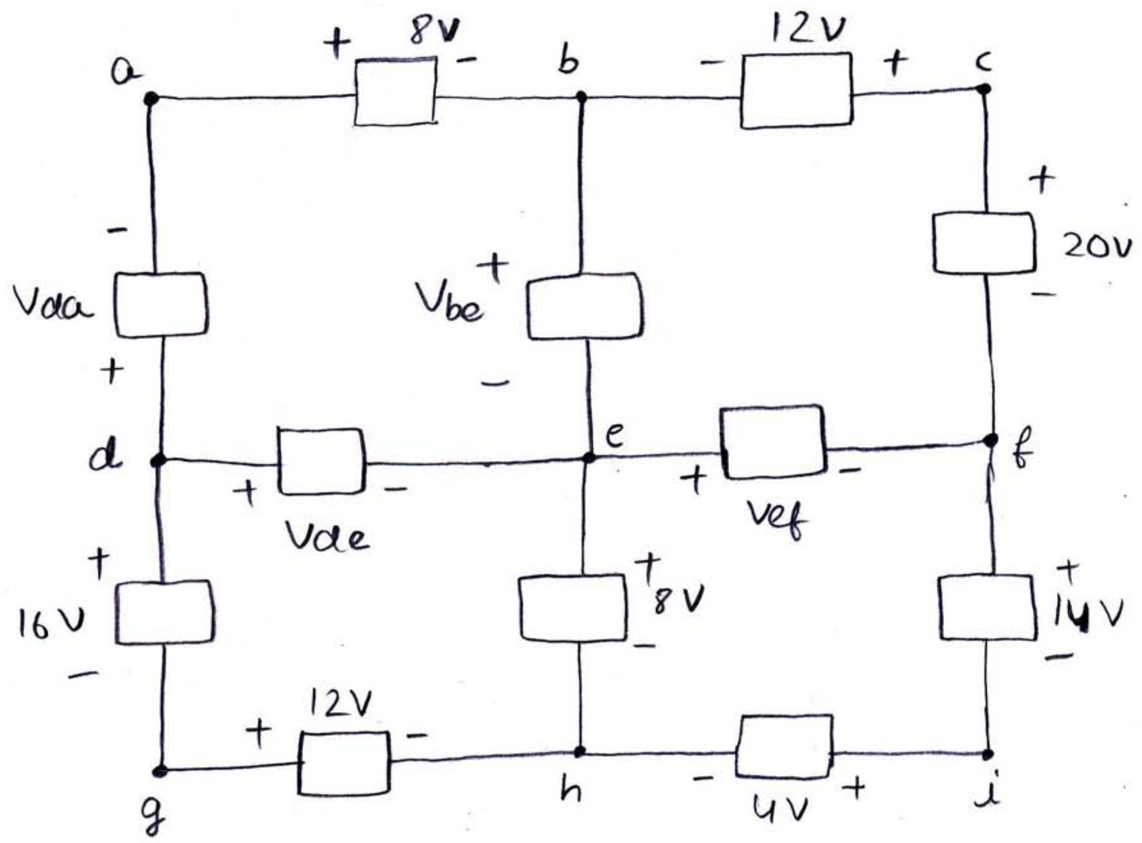
$V_{fb} = 12 - 20$

$V_{fb} = -8\,V$

KVL : $V_{dc} + V_{cf} = V_{ef} + V_{de}$

$V_{dc} = -10 + 20 - 20$

$\boxed{V_{dc} = -10\,V}$



2.22 Find V_{ac} in the circuit in Fig. P2.22.

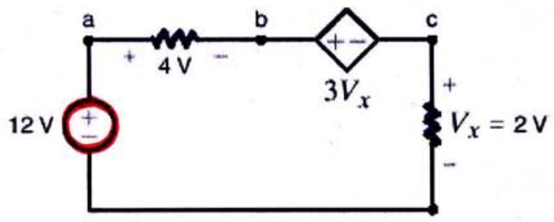


Figure P2.22

SOLUTION:

$$V_{ac} = 4 + 3V_x$$

$$V_{ac} = 4 + 3(2)$$

$$V_{ac} = 10\text{V}$$

2.23 Find V_{ad} and V_{ce} in the circuit in Fig. P2.23.

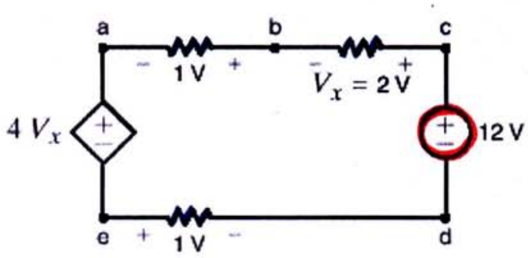


Figure P2.23

SOLUTION:

$$V_{ad} = 4V_x + 1 = 4(2) + 1$$

$$V_{ad} = 9\text{V}$$

$$12 = 1 + V_{ce}$$

$$V_{ce} = 11\text{V}$$

2.24 Find V_o in the network in the accompanying Figure.

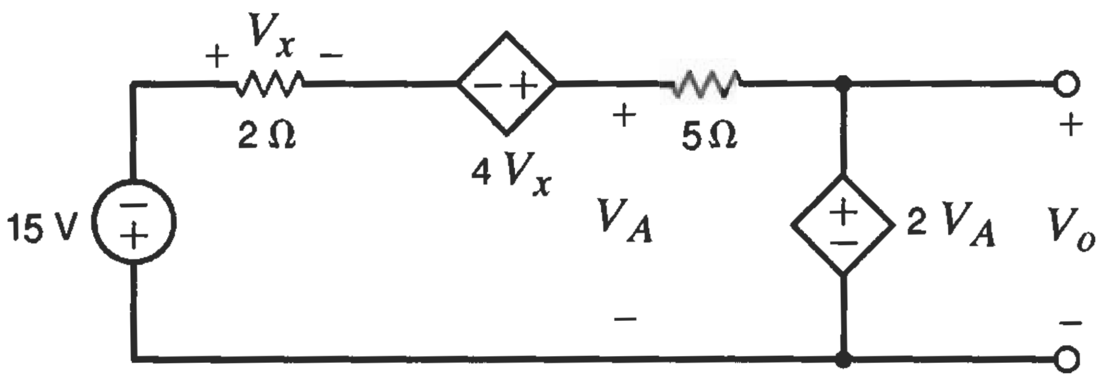
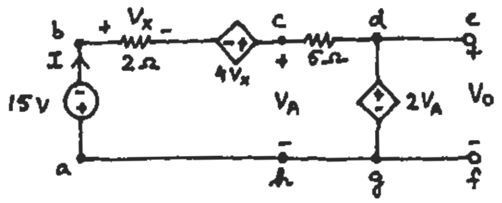


Figure P2.24

Solution: 2.24



KVL for 'abcdgha': $15 + V_x - 4V_x + 5I + 2V_A = 0$ — (1)

$V_x = 2I$ — (2)

KVL for 'cdghc' : $V_A = 5I + 2V_A \Rightarrow V_A = -5I$ — (3)

KVL for 'defgd' : $V_o - 2V_A = 0 \Rightarrow V_o = 2V_A$ — (4)

Substituting (2) + (3) in (1): $15 + 2I - 4(2I) + 5I + 2(-5I) = 0$

$15 - 11I = 0 \Rightarrow I = \frac{15}{11}$ A — (5)

Substituting (5) in (3) : $V_A = (-5)\frac{15}{11} \Rightarrow V_A = \frac{-75}{11}$ V — (6)

Substituting (6) in (4) : $V_o = 2\left(\frac{-75}{11}\right) \Rightarrow \boxed{V_o = -13.64V}$

(Value rounded off to 2 significant digits.)

2.25 Find V_o in the circuit in Fig. P2.25.

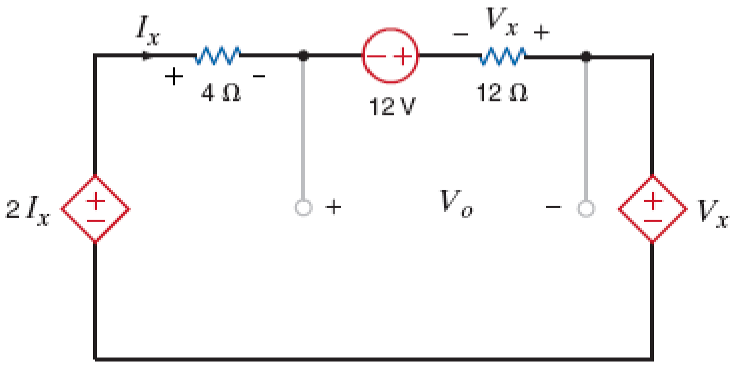


Figure P2.25

SOLUTION:

KVL:

$$V_o + 12 + V_x = 0$$

$$V_o = -V_x - 12$$

$$V_x = -12 I_x$$

KVL around outer loop:

$$2I_x + 12 + V_x = 4I_x + V_x$$

$$2I_x + 12 + 12I_x = 4I_x + 12I_x$$

$$2I_x = 12$$

$$I_x = 6\text{A}$$

$$V_x = -12(6) = -72\text{ V}$$

$$V_o = -(-72) - 12$$

$$V_o = 60\text{ V}$$

2.26 The 10-V source absorbs 2.500 mW of power. Calculate **(a)** V_{ba} and **(b)** the power absorbed by the dependent voltage source in the Figure.

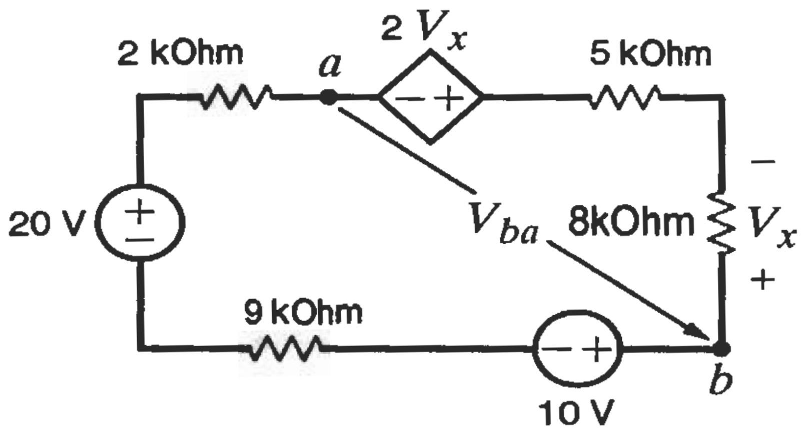
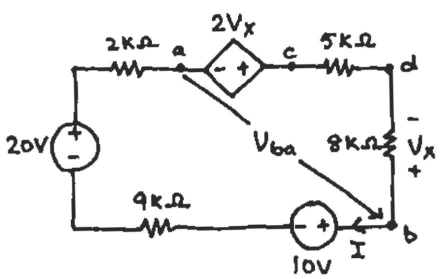


Figure P2.26

Solution: 2·26



$$P_{10V} = 2{\cdot}50 \text{ mW absorbed}$$

$$P_{10V} = 10\,I$$

$$\Rightarrow I = \frac{P_{10V}}{10} = 250\ \mu A$$

KVL for 'bacdb' : $V_{ba} - V_{ca} - V_{dc} - V_{bd} = 0$

$$\Rightarrow V_{ba} = V_{ca} + V_{dc} + V_{bd} \quad \text{— (1)}$$

$$V_{bd} = -I\,(8\times 10^3) = -(250\times 10^{-6})(8\times 10^3)$$

$$\Rightarrow V_{bd} = -2\text{ V} \quad \text{— (2)}$$

$$V_{dc} = -I\,(5\times 10^3) \Rightarrow V_{dc} = -1{\cdot}25\text{ V} \quad \text{— (3)}$$

$$V_x = V_{bd} = -2\text{ V}$$

$$V_{ca} = 2V_x = -4\text{V} \quad \text{— (4)}$$

Substituting (2), (3), (4) in (1) : $\boxed{V_{ba} = -7{\cdot}25\text{ V}}$

$$P_{DS} = -2V_x I = -2(-2)(250\times 10^{-6})$$

$$\Rightarrow \boxed{P_{DS} = 1\text{mW}}$$

2.27 Find V_{bd} in the network in Fig. P2.27.

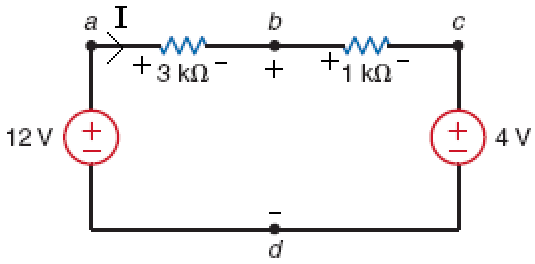


Figure P2.27

SOLUTION:

KVL: $12 = 3KI + 1KI + 4$

$4KI = 8$

$I = 2mA$

KVL left loop: $12 = 3KI + V_{bd}$

$V_{bd} = 12 - 3K(2m)$

$V_{bd} = 6V$

2.28 Find V_x in the circuit in Fig. P2.28.

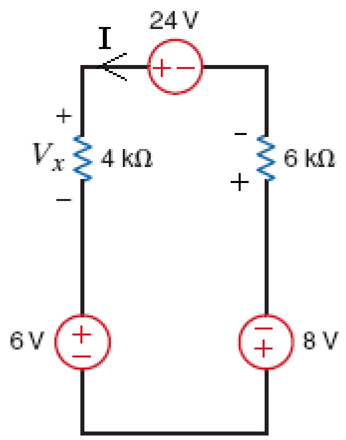


Figure P2.28

SOLUTION:

KVL:

$$24 = 4kI + 6 + 8 + 6kI$$

$$10kI = 10$$

$$I = 1mA$$

$$V_x = I(4k) = (1m)(4k)$$

$$V_x = 4V$$

2.29 Find V_{ab} in the network in Fig. P2.29.

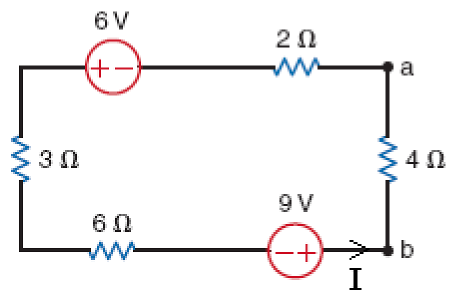


Figure P2.29

SOLUTION:

$V_{ab} = -4I$

KVL : $6 + 9 = 4I + 2I + 3I + 6I$

$15I = 15$

$I = 1A$

$V_{ab} = -4(1)$

$V_{ab} = -4V$

2.30 If $V_o = 3$ V in the circuit in Fig P2.30, find V_S.

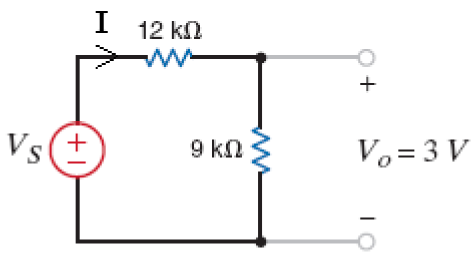


Figure P2.30

SOLUTION:

$$V_o = 9K I$$

$$I = \frac{V_o}{9K} = \frac{3}{9K}$$

$$I = \frac{1}{3} mA$$

KVL:

$$V_s = 12K I + 9K I$$

$$V_s = 21K\left(\frac{1}{3} m\right)$$

$$V_s = 7V$$

2.31 Find the power supplied by each source in the circuit in Fig. P2.31.

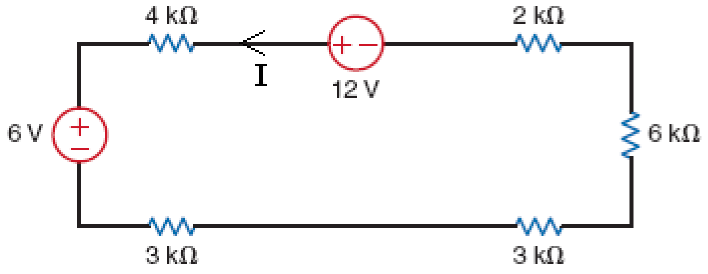


Figure P2.31

SOLUTION:

KVL: $4KI + 6 + 3KI + 3KI + 6KI + 2KI = 12$

$18KI = 6$

$I = \frac{1}{3}mA$

$P_{12V} = 12I = 12(\frac{1}{3}m)$

$P_{12V} = 4mW$ (supplied)

$P_{6V} = -6I = -6(\frac{1}{3}m) = -2mW$ (absorbed)

2.32 Find V_x and the power supplied by the 15-V source in the circuit in Fig. P2.32.

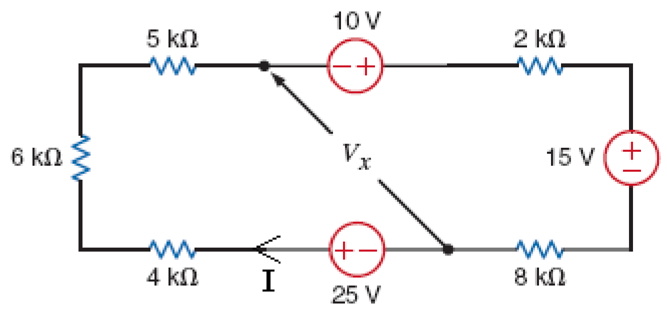


Figure P2.32

SOLUTION:

KVL : $25 + 10 = 4KI + 6KI + 5KI + 2KI + 15 + 8KI$

$25KI = 20$

$I = 0.8mA$

KVL : $V_x + 10 = 2KI + 15 + 8KI$

$V_x = 5 + 10K(0.8m)$

$V_x = 13V$

$P_{15V} = VI = 15(0.8m)$

$P_{15V} = 12\,mW$ (absorbed)

2.33 Find V_1 in the network in the accompanying Figure.

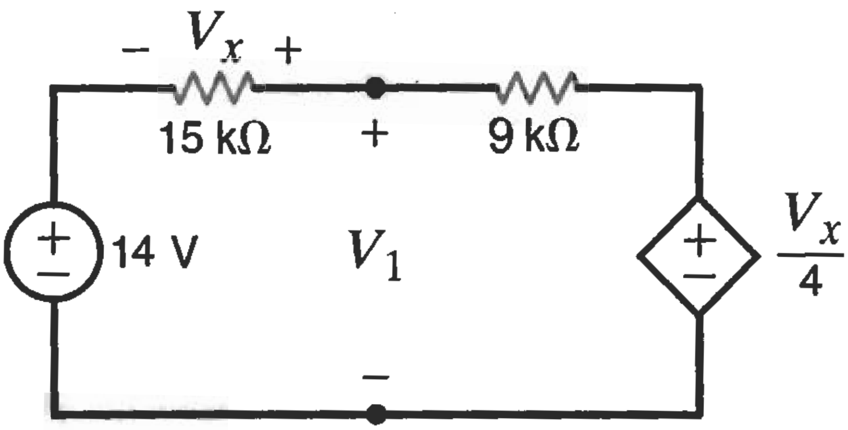
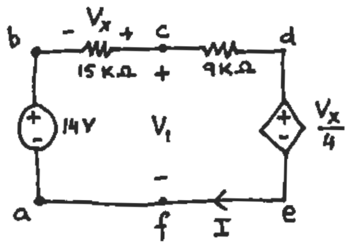


Figure P2.33

Solution: 2.33



$$V_x = -I\,(15 \times 10^3)$$

KVL for 'abcdefa': $-V_x + I(9\times10^3) + \frac{V_x}{4} - 14 = 0$

$$I\,(15\times10^3) + I(9\times10^3) - \frac{I}{4}(15\times10^3) = 14$$

$$I\,(10^3)\left(15 + 9 - \frac{15}{4}\right) = 14$$

$$\Rightarrow I = 691.36\ \mu A$$

KVL for 'cfabc' : $V_1 - 14 - V_x = 0$

$$\Rightarrow V_1 = 14 + V_x$$

$$= 14 + (-I)(15\times10^3)$$

$$= 14 - (691.36\times10^{-6})(15\times10^3)$$

$$\Rightarrow \boxed{V_1 = 3.63\ V}$$

(Value rounded off to 2 significant digits.)

2.34 Calculate the power absorbed by the dependent source in the circuit in Fig. P2.34.

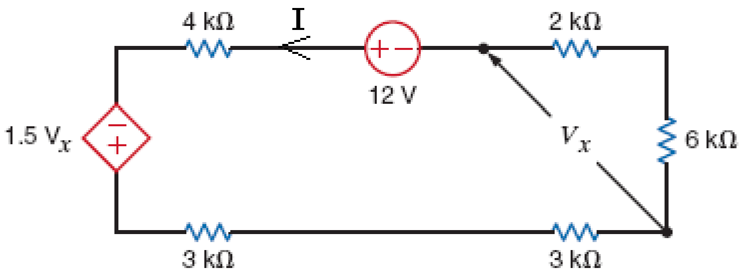


Figure P2.34

SOLUTION:

KVL : $12 + 1.5V_x = (4K + 3K + 3K + 2K)I$

$$I = \frac{12}{18k} + \frac{1.5}{18k} V_x$$

KVL : $2KI + 6KI = V_x$

$$V_x = -8KI$$

$$I = \frac{12}{18k} + \frac{1.5}{18k}(-8KI)$$

$I = 0.4mA$

$P = 1.5 V_x(I)$

$P = 1.5 V_x (0.0004)$

$P = 1.5(8K)(0.0004)(0.0004)$

$P = 1.92 mW$

2.35 Find the power absorbed by the dependent voltage source in the circuit in Fig. P2.35.

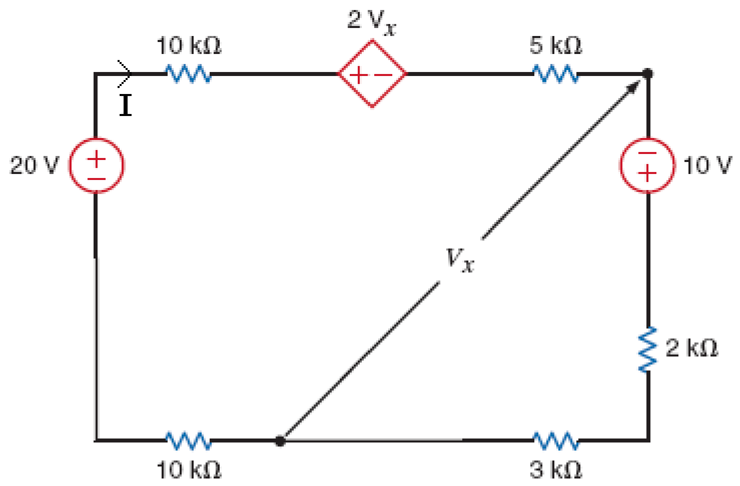


Figure P2.35

SOLUTION:

KVL: $20 + 10 = 10k\,I + 2V_x + 5k\,I + 2k\,I + 3k\,I + 10k\,I$

$30 = 30k\,I + 2V_x$

$I = 1m - \frac{1}{15}m\,V_x$

KVL: $V_x + 10 = 2k\,I + 3k\,I$

$V_x = 5k\left(1m - 1/15m\,V_x\right) - 10$

$V_x = 5 - \frac{1}{3}V_x - 10$

$3V_x = 15 - V_x - 30$

$4V_x = -15$

$V_x = -3.75\text{ V}$

$I = 1m - \frac{1}{15}m\,(-3.75)$

$I = 1.25\,mA$

$P = 2V_x\,(I)$

$P = 2(-3.75)(1.25m)$

$P = -9.375\,mW$

2.36 Find the power absorbed by the dependent source in the circuit in Fig. P2.36.

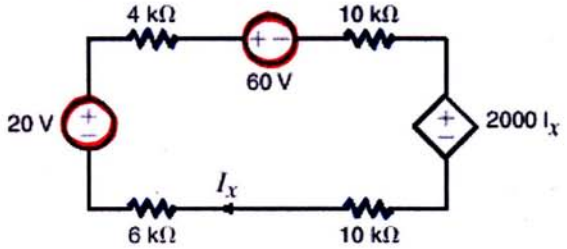


Figure P2.36

SOLUTION:

KVL:

$$20 = 6KI_x + 4KI_x + 60 + 10KI_x + 2KI_x + 10KI_x$$

$$32KI_x = -40$$

$$I_x = 1.25mA$$

$$P = (2000 I_x)(I_x)$$

$$P = \{200(-1.25m)\}(-1.25m)$$

$$P = 3.125 \, mW$$

2.37 Find I_0 in the network in Fig. P2.37.

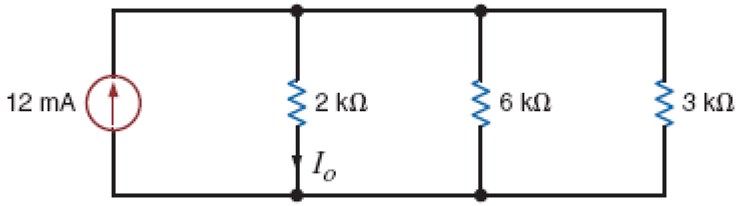
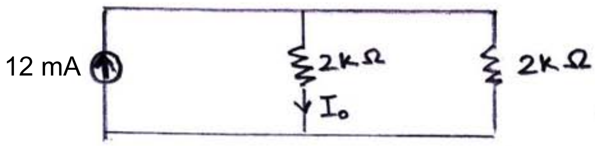


Figure P2.37

SOLUTION:

$6K \| 3K = 2K\Omega$



$$I_o = \left(\frac{2k}{2k+2k}\right)(12m)$$

$$I_o = 6mA$$

2.38 Find I_0 in the network in Fig. P2.38.

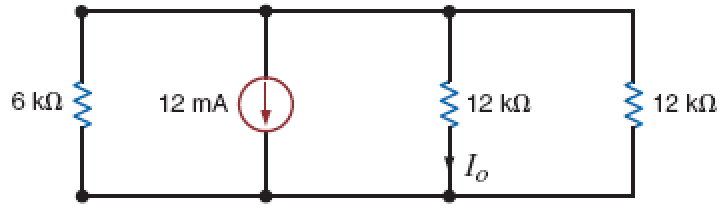
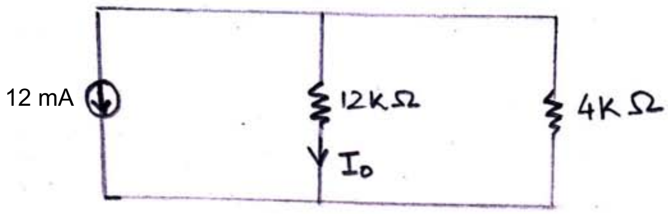


Figure P2.38

SOLUTION:

$$6K \| 12K = 4K\Omega$$



$$I_o = \left(\frac{4k}{4K+12K}\right)(-12m)$$

$$I_o = -3mA$$

2.39 Find the power supplied by each source in the circuit in Fig. P2.39.

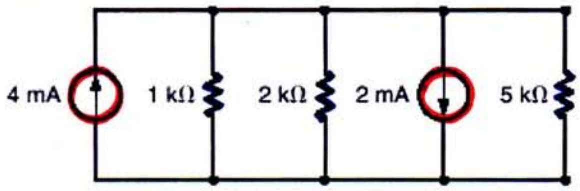
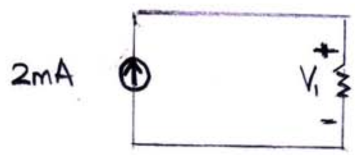


Figure P2.39

SOLUTION:

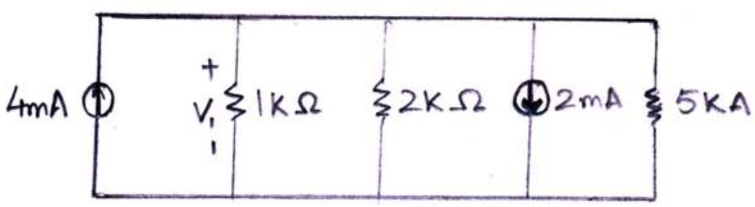


$$R_{eq} = (1k \| 2k) \| 5k$$

$$R_{eq} = 588.24\,\Omega$$

$$V_1 = 2m(588.24)$$

$$V_1 = 1.18\,V$$



$$P_{4mA} = 4m(1.18)$$

$$P_{4mA} = 4.72\,mW$$

$$P_{2mA} = (-2m)(1.18)$$

$$P_{2mA} = -2.36\,mW$$

2.40 Find the current I_A in the circuit in Fig. P2.40.

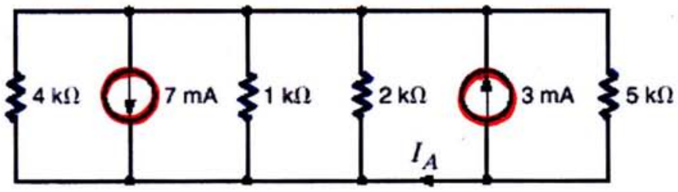
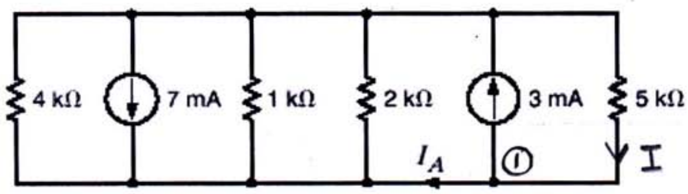
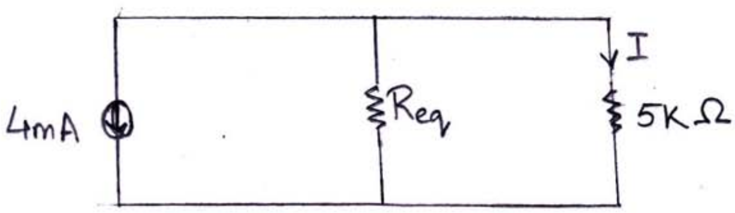


Figure P2.40

SOLUTION:





$$I = \left(\frac{R_{eq}}{R_{eq} + 5K}\right)(-4m)$$

$$I = -0.41\text{mA}$$

KCL at 1 :

$$I = 3m + I_A$$

$$I_A = -0.41m - 3m$$

$$\boxed{I_A = -3.41\text{mA}}$$

2.41 Find I_O in the network in the accompanying Figure.

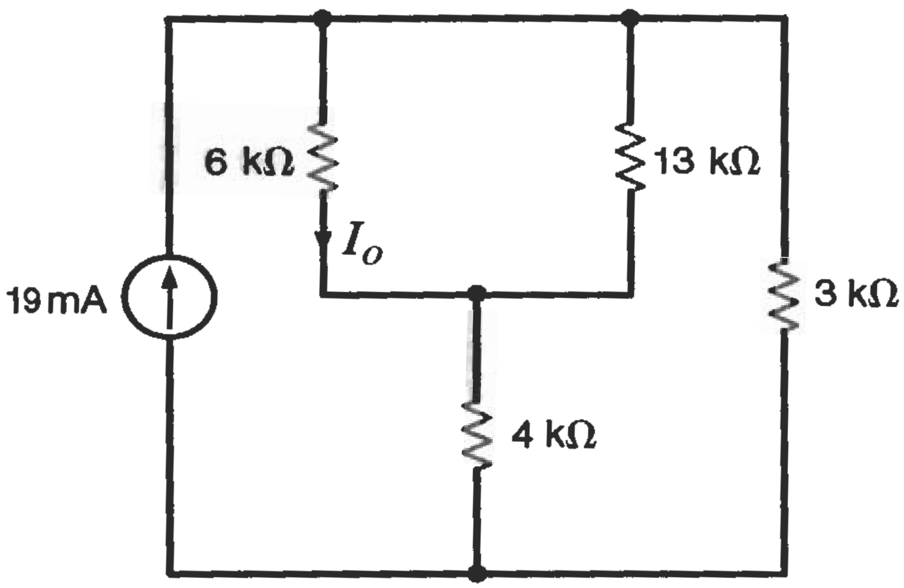
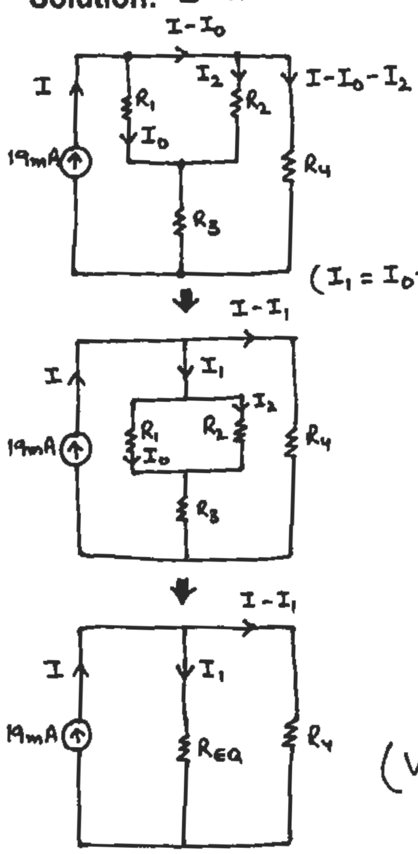


Figure P2.41

Solution: 2.41



$(I_1 = I_o + I_2)$

$R_1 = 6\,k\Omega,\ R_2 = 13\,k\Omega,\ R_3 = 4\,k\Omega,\ R_4 = 3\,k\Omega$

$$R_{EQ} = \frac{R_1 R_2}{R_1 + R_2} + R_3 = \frac{6(13)}{6+13} + 4$$

$$\Rightarrow R_{EQ} = 8.11\ k\Omega$$

$$I_1 = 19 \times 10^{-3}\left[\frac{R_4}{R_{EQ} + R_4}\right]$$

$$= 19 \times 10^{-3}\left[\frac{3}{8.11 + 3}\right] = 5.13\,mA$$

$$I_o = I_1\left[\frac{R_2}{R_1 + R_2}\right]$$

$$= 5.13 \times 10^{-3} \times \frac{13}{19}$$

$$\Rightarrow \boxed{I_o = 3.51\ mA}$$

(Value rounded off to two significant digits.)

2.42 Find I_0 in the network in Fig. P2.42.

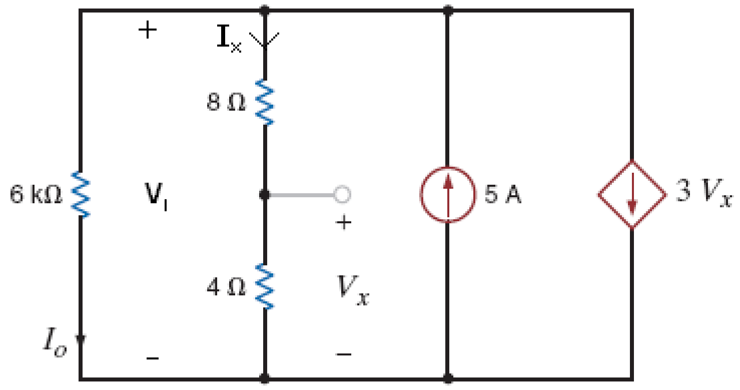


Figure P2.42

SOLUTION:

$$\text{KCL}: \quad 5 = \frac{V_1}{6} + \frac{V_1}{8+4} + 3V_x$$

$$V_x = \left(\frac{4}{4+8}\right)(V_1)$$

$$V_x = \frac{V_1}{3}$$

$$5 = \frac{V_1}{6} + \frac{V_1}{12} + 3\left(\frac{V_1}{3}\right)$$

$$60 = 2V_1 + V_1 + 12V_1$$

$$15V_1 = 60$$

$$V_1 = 4\text{ V}$$

$$V_1 = 6I_o$$

$$I_o = \frac{V_1}{6}$$

$$I_o = \frac{4}{6}$$

$$I_o = \frac{2}{3} A$$

2.43 Calculate the power absorbed by the dependent source in the circuit in Fig. P2.43.

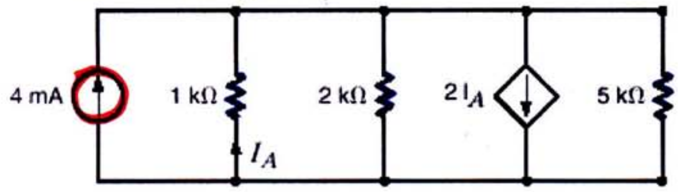
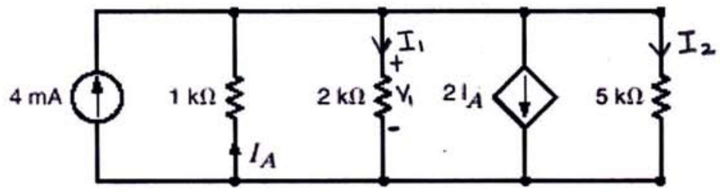


Figure P2.43

SOLUTION:



KCL: $4m + I_A = I_1 + I_2 + 2I_A$

$$I_A = -\frac{V_1}{1K}$$

$$4m - \frac{V_1}{K} = I_1 + I_2 + 2\left(\frac{-V_1}{1K}\right)$$

$$I_1 = \frac{V_1}{2K} \text{ and } I_2 = \frac{V_1}{5K}$$

$$4m - \frac{V_1}{1K} = \frac{V_1}{2K} + \frac{V_1}{5K} + 2\left(\frac{-V_1}{1K}\right)$$

$$40 - 10V_1 = 5V_1 + 2V_1 - 20V_1$$

$$V_1 = \frac{-40}{3}\,V$$

$$I_A = \frac{-\left(\frac{-40}{3}\right)}{1K} = 13.33mA$$

$$P_{2I_A} = V_1\,(2I_A) = \left(\frac{-40}{3}\right)(2)(13.33m)$$

$$P_{2I_A} = \left(\frac{-40}{3}\right)(2)\left(\frac{40}{3}\right)$$

$$= -355.55 mW$$

2.44 Determine I_L in the circuit in the Figure.

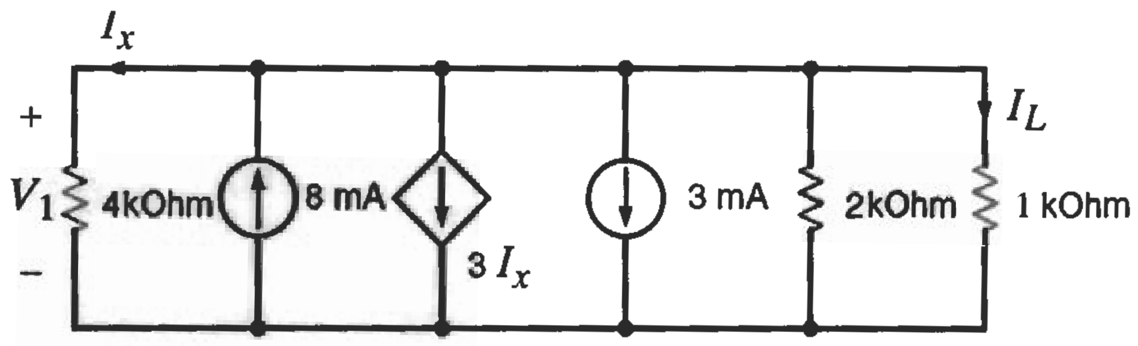


Figure P2.44

Solution: 2·44

$$I_x = \frac{V_1}{4000}$$

$$\text{KCL} : \quad I_x - 8\times10^{-3} + 3I_x + 3\times10^{-3} + \frac{V_1}{2000} + \frac{V_1}{1000} = 0$$

$$\frac{V_1}{4000} - 8\times10^{-3} + \frac{3V_1}{4000} + 3\times10^{-3} + \frac{V_1}{2000} + \frac{V_1}{1000} = 0$$

$$\frac{V_1}{1000}\left[\frac{1}{4} + \frac{3}{4} + \frac{1}{2} + 1\right] = 5\times10^{-3}$$

$$\Rightarrow \quad V_1 = 2\,V$$

$$I_L = \frac{V_1}{1000} \quad \Rightarrow \quad I_L = 2\,mA$$

2.45 Find the power absorbed by the dependent source in the network in Fig. P2.45.

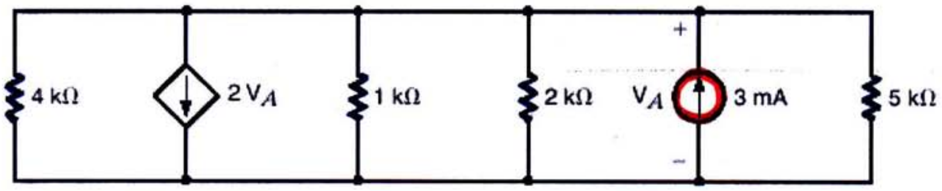
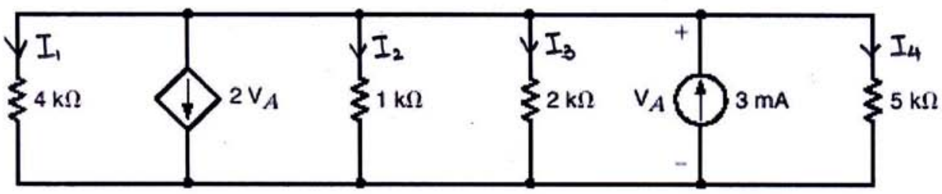


Figure P2.45

SOLUTION:



KCL: $3m = I_1 + 2V_A + I_2 + I_3 + I_4$

$$I_1 = \frac{V_A}{4K},\ I_2 = \frac{V_A}{1K},\ I_3 = \frac{V_A}{2K},\ \text{and}\ I_4 = \frac{V_A}{5K}$$

$$3m = \frac{V_A}{4K} + 2V_A + \frac{V_A}{1K} + \frac{V_A}{2K} + \frac{V_A}{5K}$$

$$60 = 5V_A + 40KV_A + 20V_A + 10V_A + 4V_A$$

$$V_A = 1.5mV$$

$$P_{2VA} = V_A I = V_A(2V_A)$$

$$P_{2VA} = 1.5m(2)(1.5m)$$

$$P_{2VA} = 4.5\mu W$$

2.46 Find R_{AB} in the circuit in the accompanying Figure.

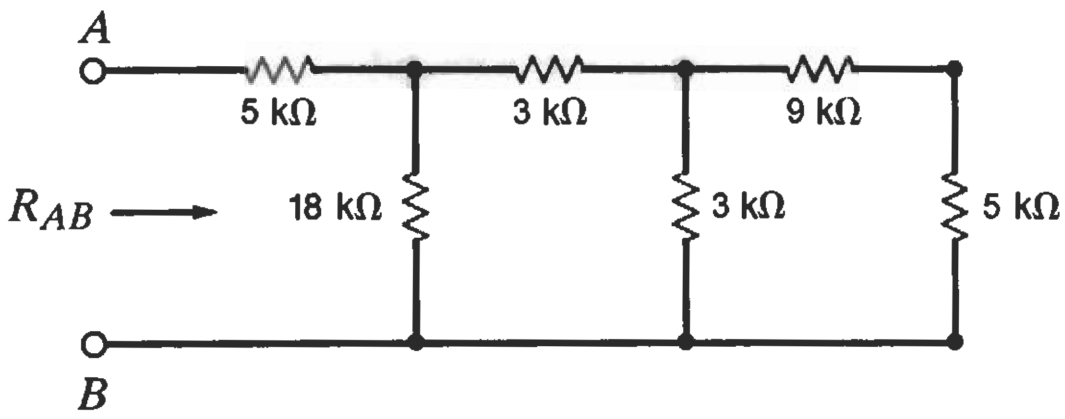
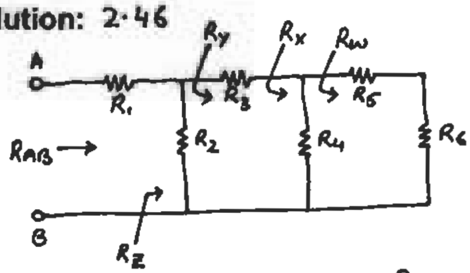


Figure P2.46

Solution: 2.46



$R_1 = 5\,k\Omega$, $R_2 = 18\,k\Omega$, $R_3 = 3\,k\Omega$,
$R_4 = 3\,k\Omega$, $R_5 = 9\,k\Omega$, $R_6 = 5\,k\Omega$

$$R_w = R_5 + R_6 = 14\,k\Omega$$

$$R_x = R_4 \parallel R_w = \frac{3(14)}{3+14} = 2.47\,k\Omega$$

$$R_y = R_3 + R_x = 5.47\,k\Omega$$

$$R_z = R_2 \parallel R_y = \frac{18\,(5.47)}{18 + 5.47} = 4.20\,k\Omega$$

$$R_{AB} = R_1 + R_z = 9.20\,k\Omega$$

$$\Rightarrow \boxed{R_{AB} = 9.20\,k\Omega}$$

(Value rounded off to 2 significant digits.)

2.47 Find R_{AB} in the network in the accompanying Figure.

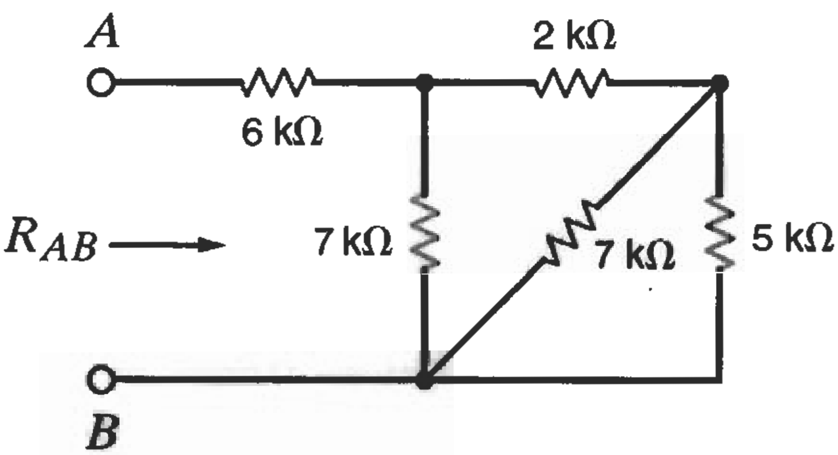
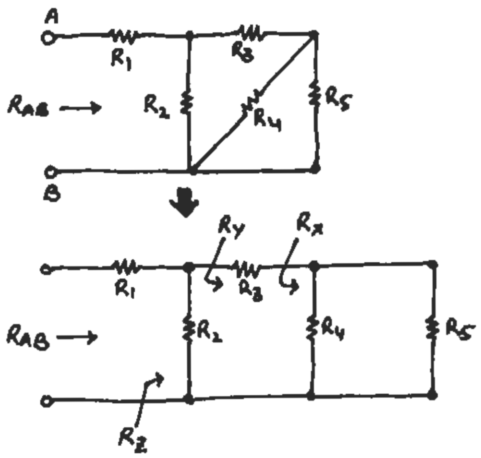


Figure P2.47

Solution: 2.47



$R_1 = 6\,k\Omega$, $R_2 = 7k\Omega$, $R_3 = 2k\Omega$,
$R_4 = 7k\Omega$, $R_5 = 5k\Omega$

$$R_x = R_4 \parallel R_5 = \frac{7(5)}{12} = 2.92\,k\Omega$$

$$R_y = R_3 + R_x = 4.92\,k\Omega$$

$$R_z = R_2 \parallel R_y = \frac{7(4.92)}{11.92} = 2.89\,k\Omega$$

$$R_{AB} = R_1 + R_z = 8.89\,k\Omega$$

$$\Rightarrow \boxed{R_{AB} = 8.89\,k\Omega}$$

(Value rounded off to 2 significant digits.)

2.48 Find R_{AB} in the circuit in the accompanying Figure.

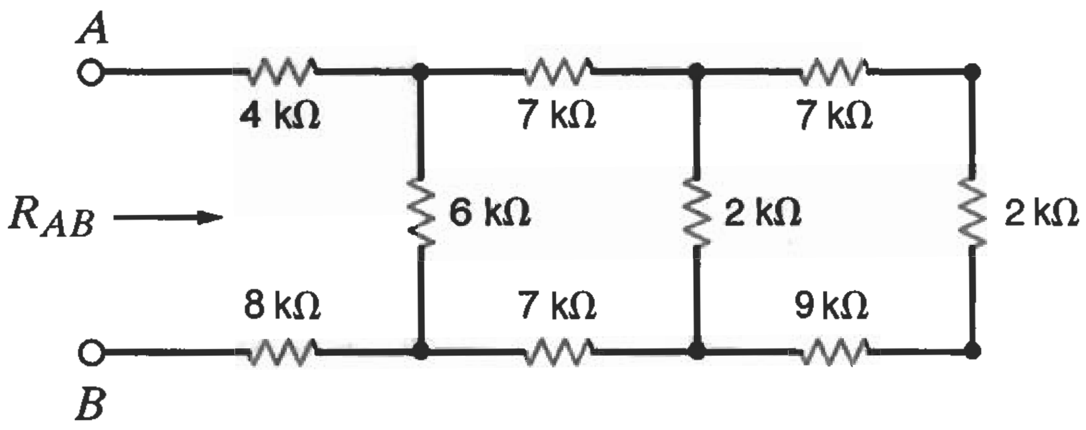
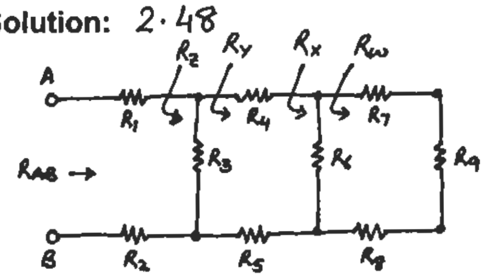


Figure P2.48

Solution: 2.48



$R_1 = 4\,k\Omega$, $R_2 = 8\,k\Omega$, $R_3 = 6\,k\Omega$,
$R_4 = 7\,k\Omega$, $R_5 = 7\,k\Omega$, $R_6 = 2\,k\Omega$,
$R_7 = 7\,k\Omega$, $R_8 = 9\,k\Omega$, $R_9 = 2\,k\Omega$

$$R_w = R_7 + R_8 + R_9 = 18\,k\Omega$$

$$R_x = R_6 \parallel R_w = \frac{2(18)}{2+18} = 1.8\,k\Omega$$

$$R_y = R_4 + R_x + R_5 = 15.8\,k\Omega$$

$$R_z = R_3 \parallel R_y = \frac{6(15.8)}{6+15.8} = 4.35\,k\Omega$$

$$R_{AB} = R_1 + R_2 + R_z$$

$$\Rightarrow \boxed{R_{AB} = 16.35\,k\Omega}$$

(Value rounded off to 2 significant digits.)

2.49 Find R_{AB} in the network in Fig. P2.49.

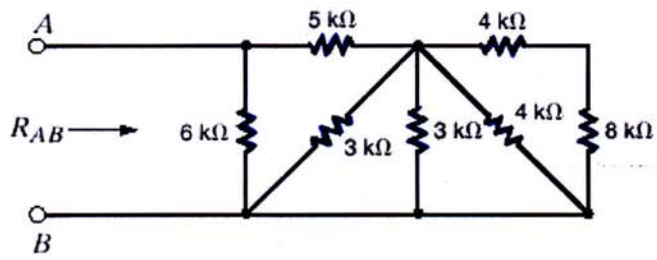


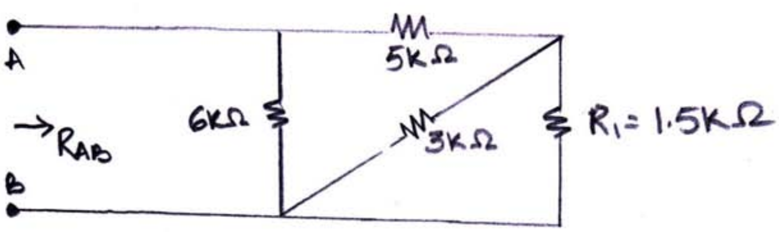
Figure P2.49

SOLUTION:

$$R_1 = [(4k + 8k) \| 4k] \| 3k$$

$$R_1 = \left(\frac{12k\,(4k)}{12k + 4k}\right) \| 3k$$

$$R_1 = 1.5k\ \Omega$$



$$R_{AB} = [(1.5k \| 3k) + 5k] \| 6k$$

$$R_{AB} = \left(\frac{1.5k\,(3k)}{1.5k + 3k} + 5k\right) \| 6k$$

$$R_{AB} = 3K\ \Omega$$

2.50 Find R_{AB} in the circuit in Fig. P2.50.

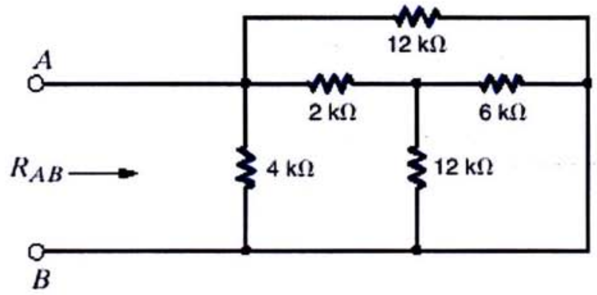
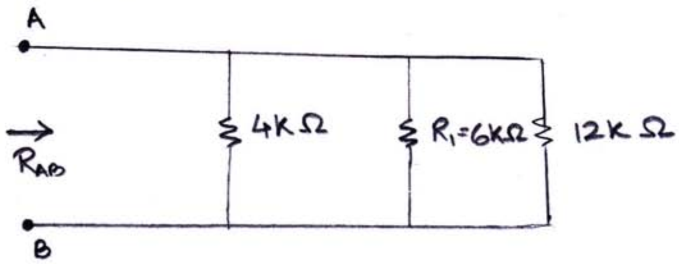


Figure P2.50

SOLUTION:

$$R_1 = (12K \| 6K) + 2K$$

$$R_1 = 6K\Omega$$



$$R_{AB} = (4K \| 6K) \| 12K$$

$$R_{AB} = 2.4K \| 12K$$

$$R_{AB} = 2K\Omega$$

2.51 Find R_{AB} in the network in Fig. P2.51.

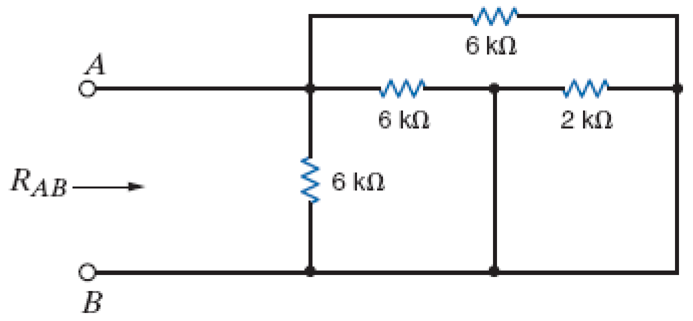
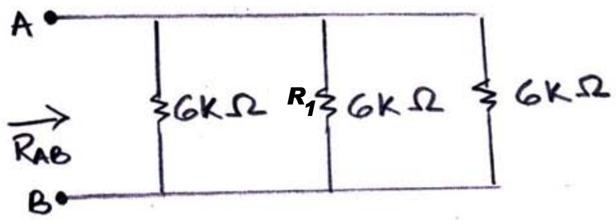


Figure P2.51

SOLUTION:

$R_1 = (2K \| 0) + 6K$

$R_1 = 6K\ \Omega$



$R_{AB} = (6K \| 6K) \| 6K$

$R_{AB} = 3K \| 6K$

$R_{AB} = 2K\ \Omega$

2.52 Find R_{AB} in the circuit in Fig. P2.52.

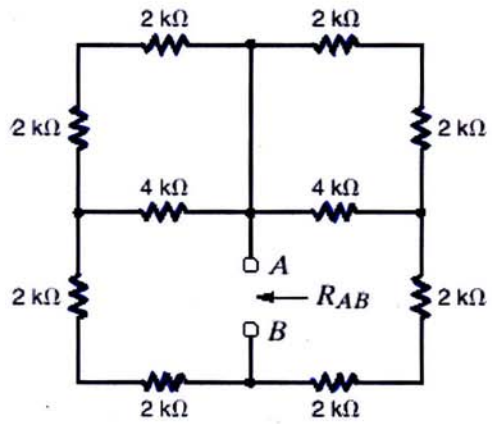
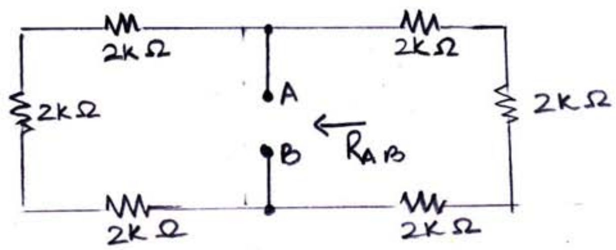
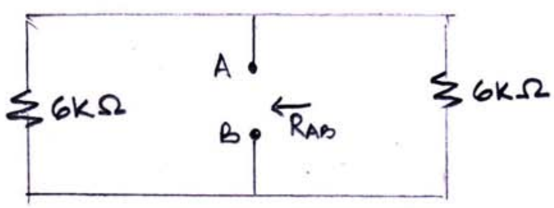


Figure P2.52

SOLUTION:





$R_{AB} = 6K \| 6K$

$R_{AB} = 3K\,\Omega$

2.53 Find the equivalent resistance, R_{eq}, in the network in Fig. P2.53.

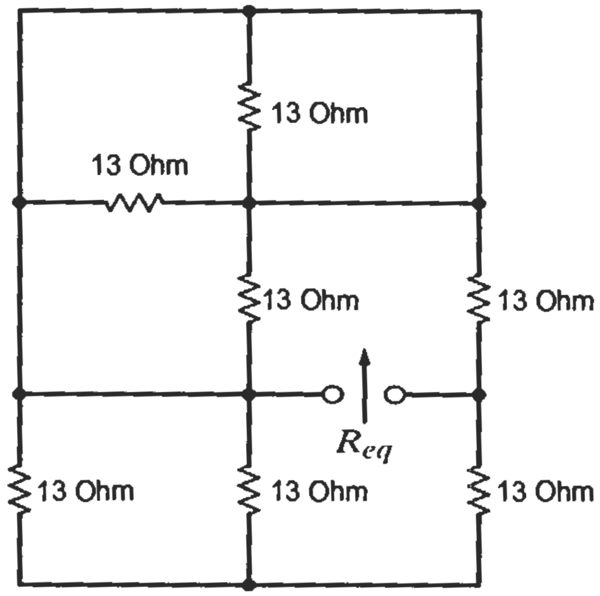
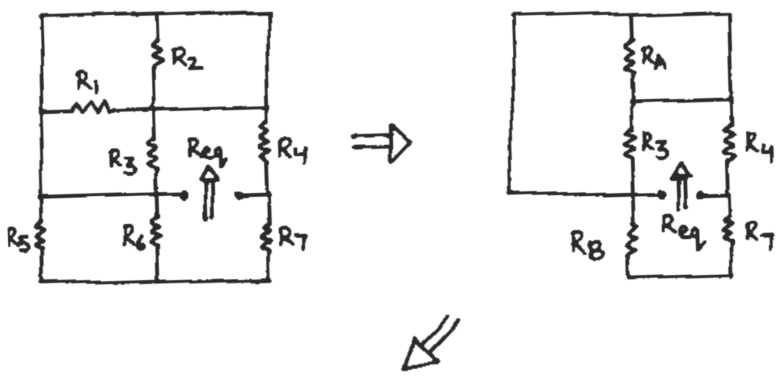


Figure P2.53

Solution: 2.53



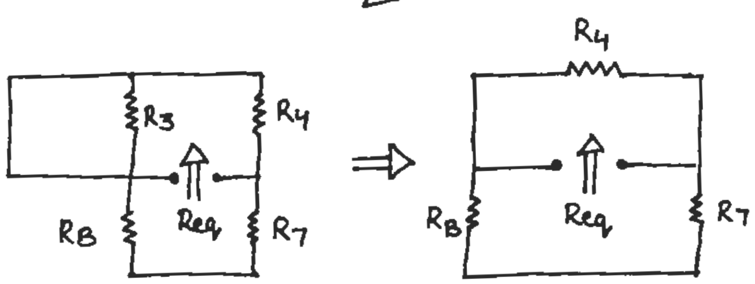
$R_A = R_1 \| R_2$

$R_B = R_5 \| R_6$

Note: R_A is shorted

$\therefore$ R_A is inactive

$R_B = 6.5$ Ohm



R_3 also shorted

$\therefore$ R_3 is inactive

$R_{eq} = R_4 \| (R_B + R_7)$

$\boxed{R_{eq} = 7.8 \text{ Ohm}}$

2.54 Find the equivalent resistance looking in at terminals a-b in the circuit in Fig. P2.54.

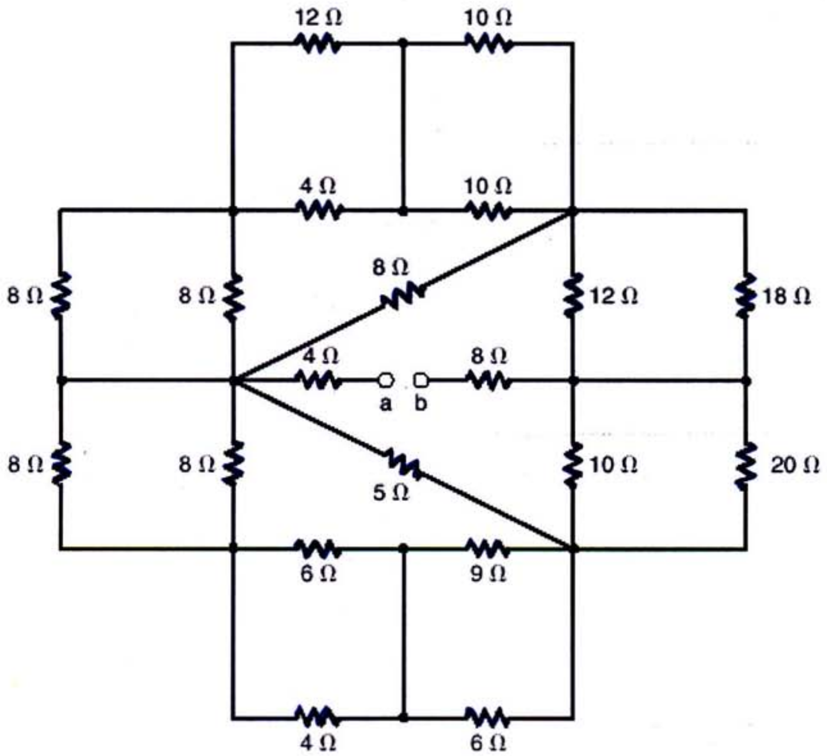
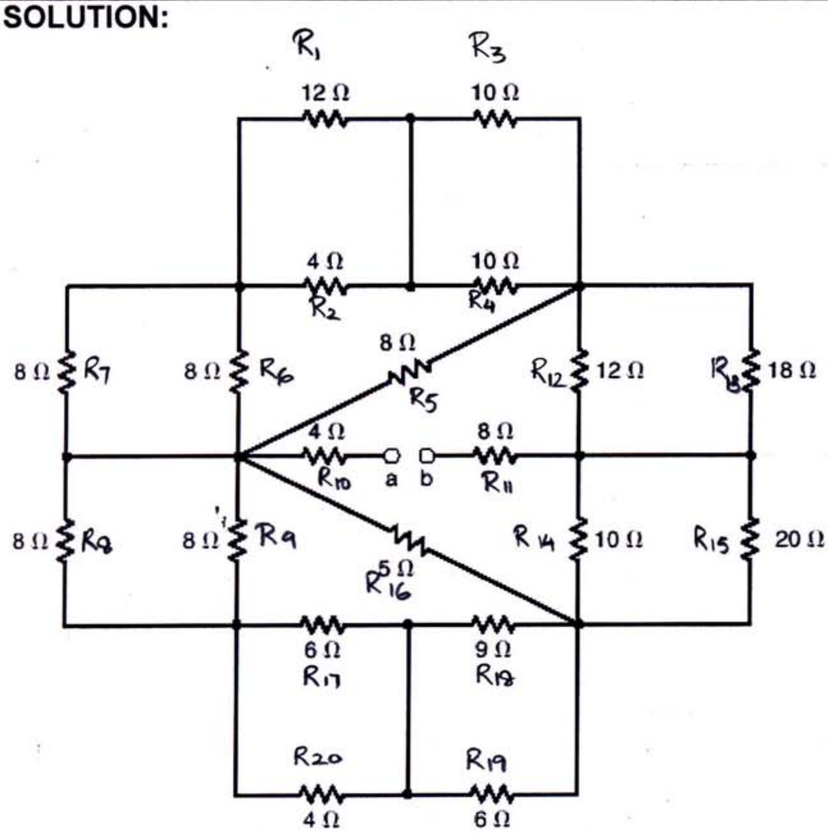


Figure P2.54

SOLUTION:



$$R_a = R_1 \| R_2 = 12 \| 4 = 3\,\Omega$$

$$R_b = R_3 \| R_4 = 10 \| 10 = 5\,\Omega$$

$$R_c = R_7 \| R_6 = 8 \| 8 = 4\,\Omega$$

$$R_d = R_{12} \| R_{13} = 12 \| 18 = 7.2\,\Omega$$

$$R_e = R_8 \| R_9 = 8 \| 8 = 4\,\Omega$$

$$R_f = R_{14} \| R_{15} = 10 \| 20 = 6.67\,\Omega$$

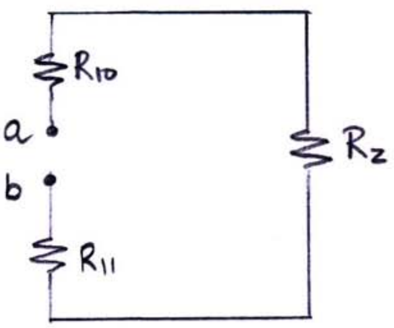
$$R_g = R_{17} \| R_{20} = 6 \| 4 = 2.4\,\Omega$$

$$R_h = R_{18} \| R_{19} = 9 \| 6 = 3.6\,\Omega$$

$$R_z = (R_x + R_d) \| (R_y + R_f)$$

$$R_z = (4.8 + 7.2) \| (3.33 + 6.67)$$

$$R_z = 12 \| 10 = 5.45\,\Omega$$



$$R_{ab} = R_{10} + R_{11} + R_2 = 4 + 8 + 5.45$$

$$R_{ab} = 17.45\ \Omega$$

2.55 Given the resistor configuration shown in Fig. P2.55, find the equivalent resistance between the following sets of terminals: (1) a and b, (2) b and c, (3) a and c, (4) d and e, (5) a and e, (6) c and d, (7) a and d, (8) c and e, (9) b and d, and (10) b and e.

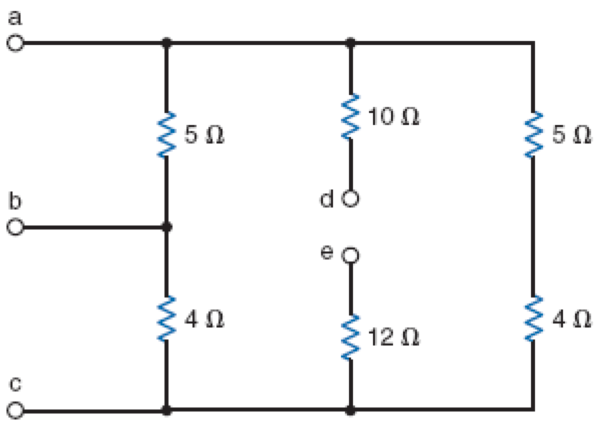
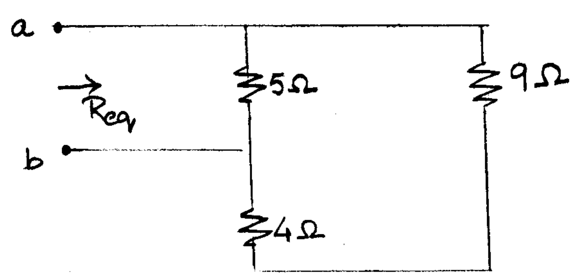


Figure P2.55

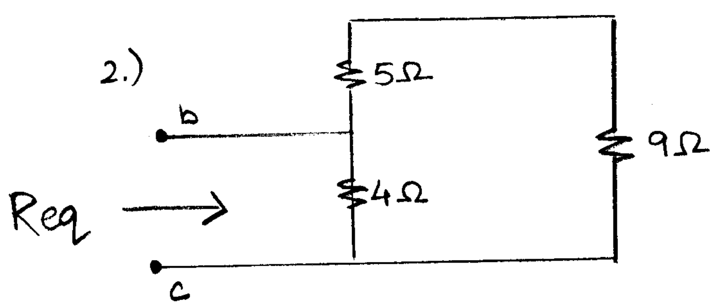
SOLUTION:

1.)



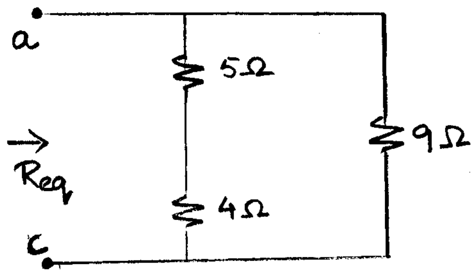
$$R_{eq} = (9+4)\,||\,5 = 3.61\ \Omega$$

2.)



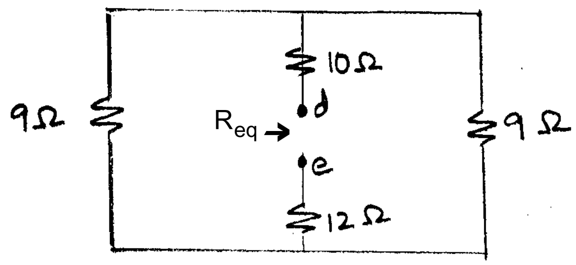
$$R_{eq} = 14\,||\,14 = 3.11\ \Omega$$

3.)



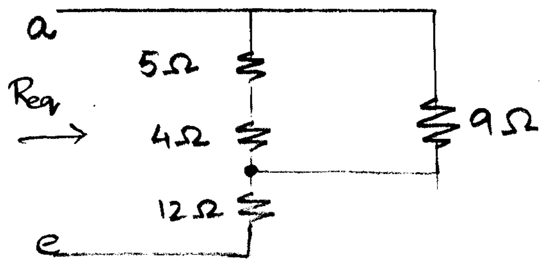
$R_{eq} = 9 \| 9 = 4.5\ \Omega$

4.)



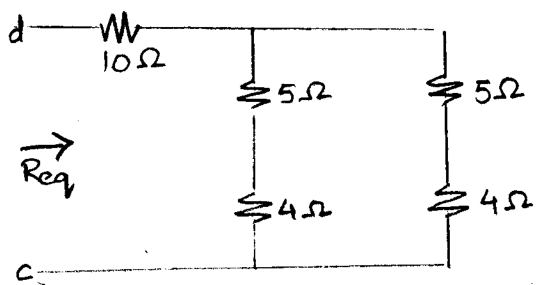
$R_{eq} = (9 \| 9) + 10 + 12 = 26.5\ \Omega$

5.)



$R_{eq} = [9 \| (5+4)] + 12 = (9 \| 9) + 12 = 16.5\ \Omega$

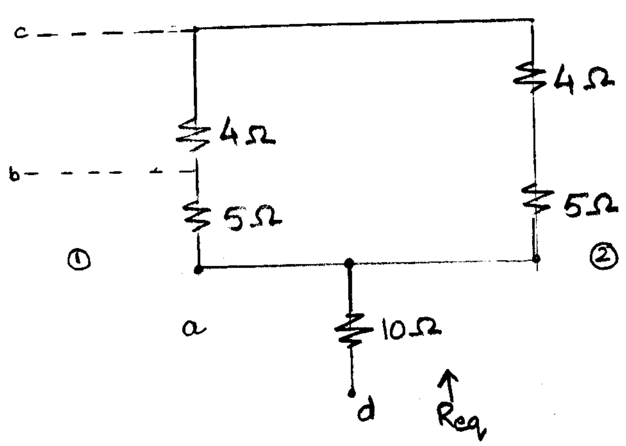
6.)

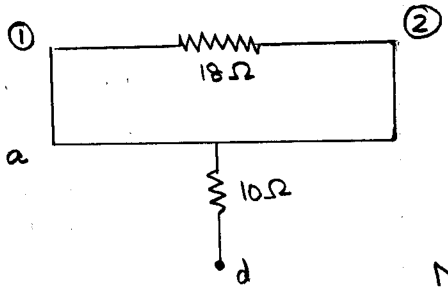


$R_{eq} = (9 \| 9) + 10$

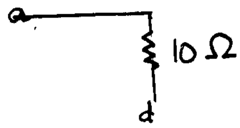
$R_{eq} = 14.5\ \Omega$

7)



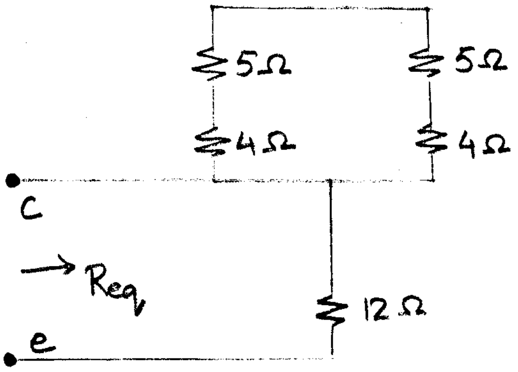


Node ① and ② are shorted.



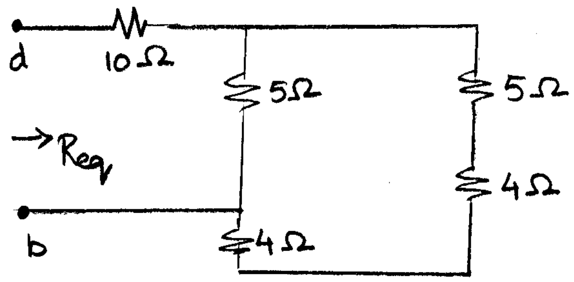
= $R_{eq} = 10\,\Omega$

8.)



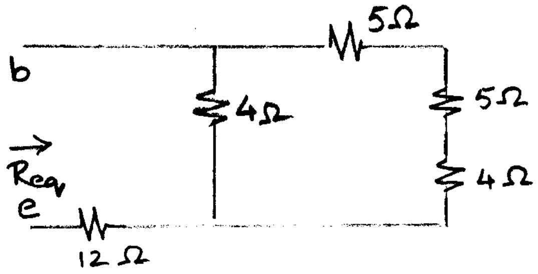
$R_{eq} = 12\ \Omega$

9.)



$$R_{eq} = (13 \| 5) + 10 = 13.61\ \Omega$$

10.)



$$R_{eq} = (14 \| 4) + 12$$

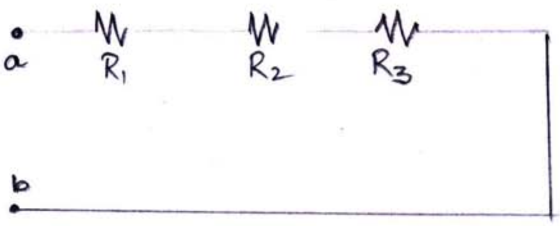
$$R_{eq} = \frac{4(14)}{4+14} + 12$$

$$R_{eq} = 15.11\ \Omega$$

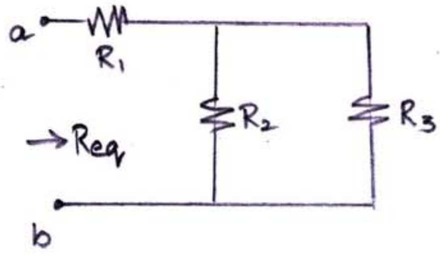
2.56 Seventeen possible equivalent resistance values may be obtained using three resistors. Determine the seventeen different values if you are given resistors with standard values: 47 Ω, 33 Ω, and 15 Ω.

SOLUTION:

$R_1 = 47\Omega$, $R_2 = 33\Omega$, and $R_3 = 15\Omega$

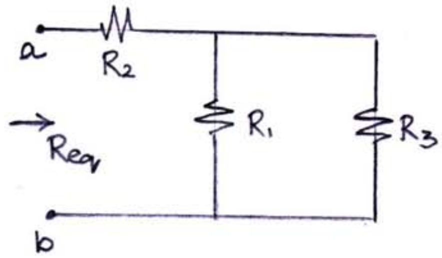


$$R_{eq} = R_1 + R_2 + R_3 = 95\Omega$$



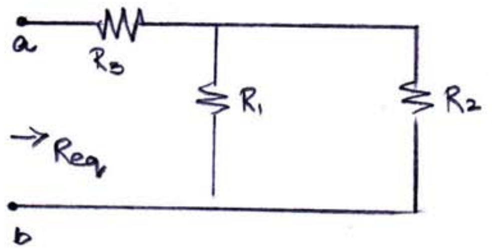
$$R_{eq} = R_1 + (R_2 \| R_3) = 47 + \frac{33(15)}{33+15}$$

$$R_{eq} = 57.31\ \Omega$$



$$R_{eq} = R_2 + (R_1 \| R_3) = 33 + \frac{47(15)}{47+15}$$

$$R_{eq} = 44.37\Omega$$



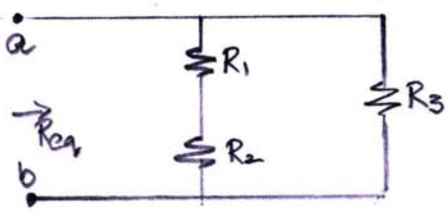
$$R_{eq} = R_3 + (R_1 \| R_2) = 15 + \frac{47(33)}{47+33}$$

$$R_{eq} = 34.39\,\Omega$$

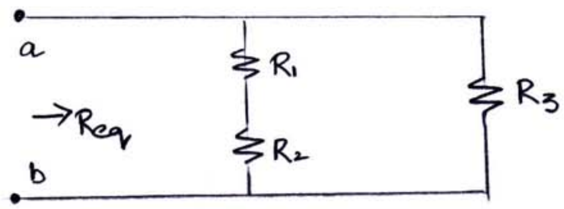
$$R_{eq} = R_1 \| R_2 \| R_3 = 47 \| 33 \| 15$$

$$R_{eq} = \frac{47(33)}{47+33} \| 15$$

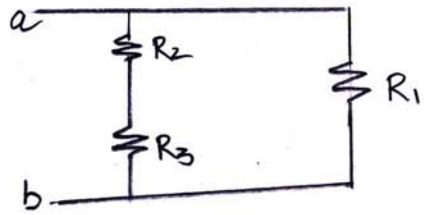
$$R_{eq} = 19.39 \| 15 = 8.46\,\Omega$$



$$R_{eq} = (R_1 + R_2) \| R_3 = 80 \| 15 = 12.63\,\Omega$$

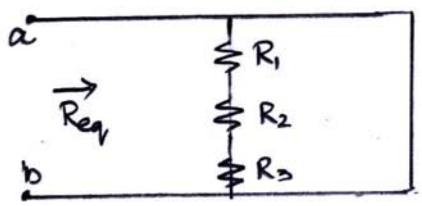


$$R_{eq} = (R_1 + R_3) \| R_2 = 62 \| 33 = 21.54\,\Omega$$



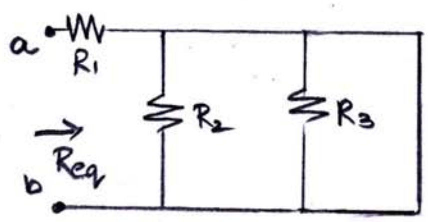
$$R_{eq} = (R_2 + R_3) \| R_1 = 48 \| 47$$

$$R_{eq} = 23.75\ \Omega$$



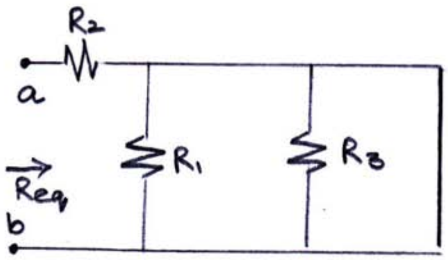
$$R_{eq} = (R_1 + R_2 + R_3) \| 0$$

$$R_{eq} = 0\,\Omega$$



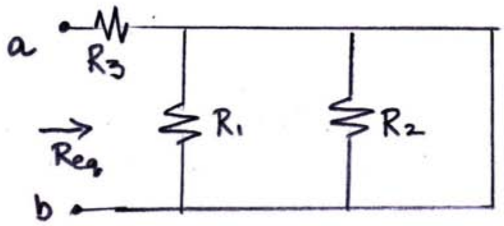
$$R_{eq} = R_1 + (R_2 \| R_3 \| 0)$$

$$R_{eq} = R_1 = 47\,\Omega$$



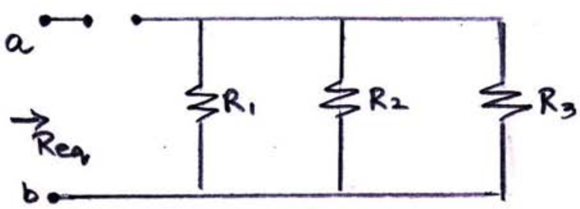
$$R_{eq} = R_2 + (R_1 \| R_3 \| 0)$$

$$R_{eq} = R_2 = 33\,\Omega$$

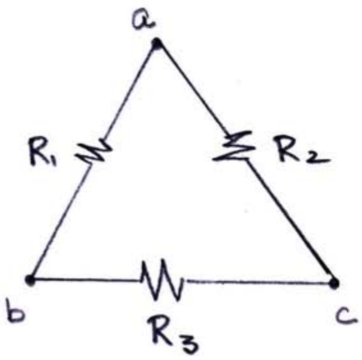


$$R_{eq} = R_3 + (R_1 \| R_2 \| 0)$$

$$R_{eq} = R_3 = 15\,\Omega$$



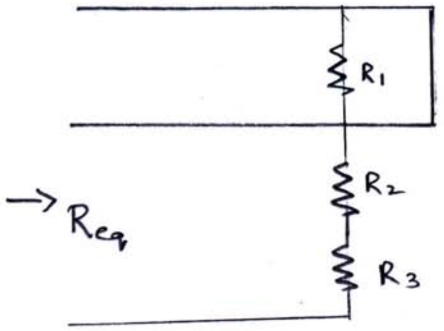
$$R_{eq} = \infty$$



$$R_{ab} = \frac{R_2(R_1+R_3)}{R_2+R_1+R_3} = \frac{33(47+15)}{33+47+15} = 21.53\,\Omega$$

$$R_{bc} = \frac{R_3(R_1+R_2)}{R_3+R_1+R_2} = \frac{15(47+33)}{15+47+33} = 12.63\,\Omega$$

$$R_{ca} = \frac{R_1(R_2+R_3)}{R_1+R_2+R_3} = \frac{47(33+15)}{47+33+15} = 23.75\,\Omega$$



$$(R_1 \| 0) + R_2 + R_3$$

$$= R_2 + R_3$$

2.57 Find the range of resistance for the following resistors.

1. 1 kΩ with a tolerance of 5% [(a) R_{min} and (b)R_{max}]
2. 670 Ω with a tolerance of 2% [(c) R_{min} and (d) R_{max}]
3. 12 kΩ with a tolerance of 10% [(e) R_{min} and (f) R_{max}]

Solution: 2.57

1. $R = 1\ k\Omega$ @ $\pm 5\%$

$R_{min} = R(1 - tol) = 1000(0.95) = 950\,\Omega$

$R_{max} = R(1 + tol) = 1000(1.05) = 1050\,\Omega$

2. $R = 670\,\Omega$ @ $\pm 2\%$

$R_{min} = 670(0.98) = 656.60\,\Omega$

$R_{max} = 670(1.02) = 683.40\,\Omega$

3. $R = 12\,k\Omega$ @ $\pm 10\%$

$R_{min} = 12 \times 10^3 (0.9) = 10.8\ k\Omega$

$R_{max} = 12 \times 10^3 (1.1) = 13.2\ k\Omega$

2.58 Given the network in Fig. P2.58, find the possible range of values for the current and power dissipated by the following resistors.

1. 180Ω with a tolerance of 1% [(a) I_{min}, and (b)I_{max}, (c) P_{min}, and (d)P_{max}]
2. 660Ω with a tolerance of 2% [(e) I_{min}, and (f)I_{max}, (g) P_{min}, and (h)P_{max}]

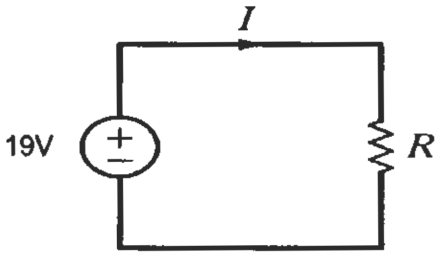


Figure P2.58

Solution: 2.58

1. $R = 180\,\Omega$ @ 1%

$I = \frac{19}{R}$ $\quad I_{max} = \frac{19}{R_{min}}$ $\quad I_{min} = \frac{19}{R_{max}}$

$R_{min} = 180\,(0.99) = 178.2\,\Omega$

$R_{max} = 180\,(1.01) = 181.8\,\Omega$

(a) $I_{min} = \frac{19}{181.8} = 104.51\ mA = 105\ mA$

(b) $I_{max} = \frac{19}{178.2} = 106.62\ mA = 107\ mA$

(c) $P_{min} = 19\,(I_{min}) = 19\,(104.51) = 1985.69 = 1986\ mW$

(d) $P_{max} = 19\,(I_{max}) = 19\,(106.62) = 2025.78 = 2026\ mW$

$\boxed{I_{min} = 105\ mA}$ $\quad \boxed{P_{min} = 1986\ mW}$

$\boxed{I_{max} = 107\ mA}$ $\quad \boxed{P_{max} = 2026\ mW}$

2. $R = 660\,\Omega$ @ $\pm 2\%$

$R_{min} = 660(0.98) = 646.8\ \Omega$

$R_{max} = 660(1.02) = 673.2\ \Omega$

(e) $I_{min} = \frac{19}{673.2} = 28.22\ mA$

(f) $I_{max} = \frac{19}{646.8} = 29.38\ mA$

(g) $P_{min} = 19(28.22) = 536.18\ mW = 536\ mW$

(h) $P_{max} = 19(29.4) = 558.6\ mW = 558\ mW$

$\boxed{I_{min} = 28.2\ mA}$ $\boxed{P_{min} = 536\ mW}$

$\boxed{I_{max} = 29.4\ mA}$ $\boxed{P_{max} = 558\ mW}$

2.59 Find I_1 and V_0 in the circuit in Fig. P2.59.

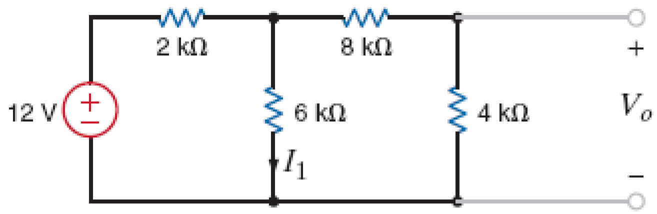
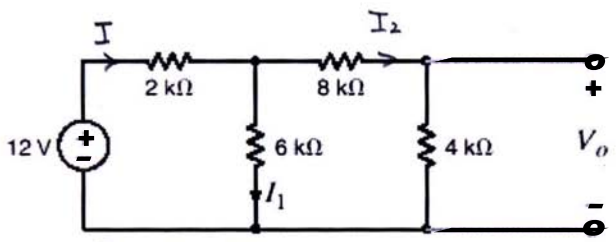


Figure P2.59

SOLUTION:



$R = 12K \| 6K$

$R = 4K\ \Omega$

$I = \frac{12}{2K+4K}$

$I = 2mA$

$I_1 = \left(\frac{8K+4K}{8K+4K+6K}\right)(2m)$

$I_1 = 1.33\ mA$

KCL:

$$I = I_1 + I_2$$

$$I_2 = 2m - 1.33m$$

$$I_2 = 0.667\,mA$$

$$V_o = I_2(4k)$$

$$V_o = 0.667(4k)$$

$$V_o = 2.67V$$

2.60 Find I_1 and V_0 in the circuit in Fig. P2.60.

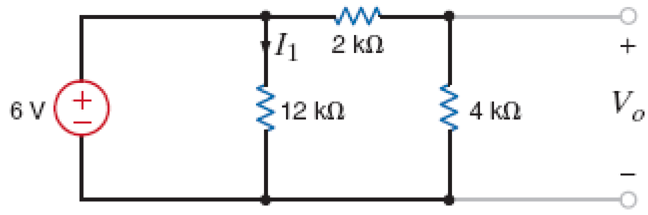
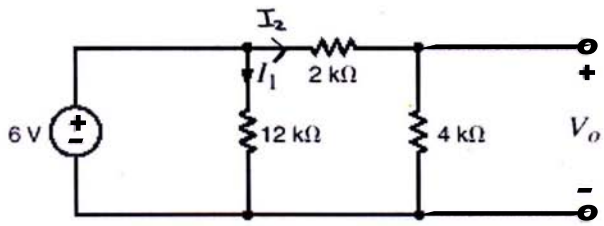


Figure P2.60

SOLUTION:



$$I_1 = \frac{6}{2k} = 0.5 \text{ mA}$$

$$I_2 = \frac{6}{2k+4k} = 1 \text{mA}$$

$$V_o = I_2(4K) = 1m(4k)$$

$$V_o = 4 \text{ V}$$

2.61 Find V_{ab} and V_{dc} in the circuit in Fig. P2.61.

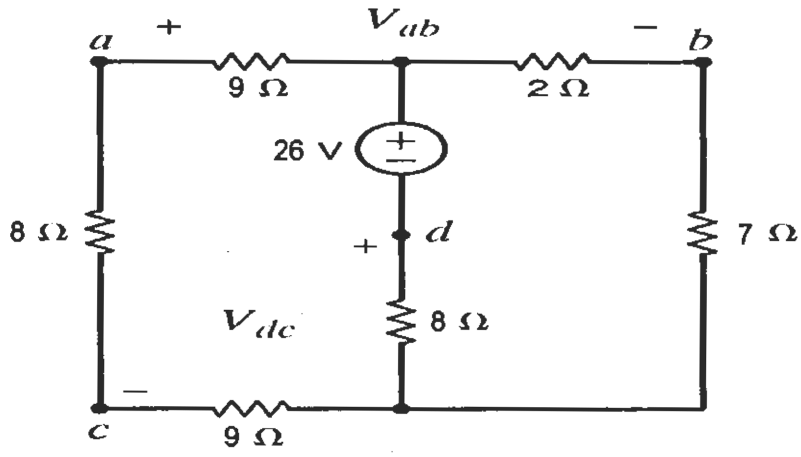
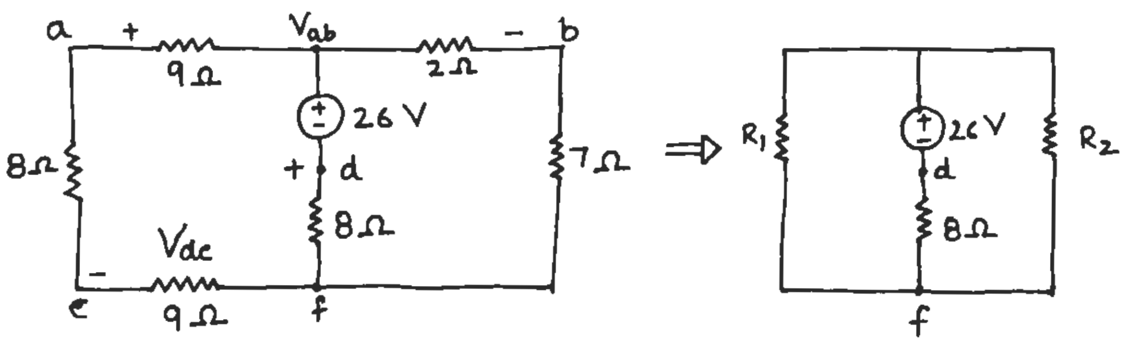


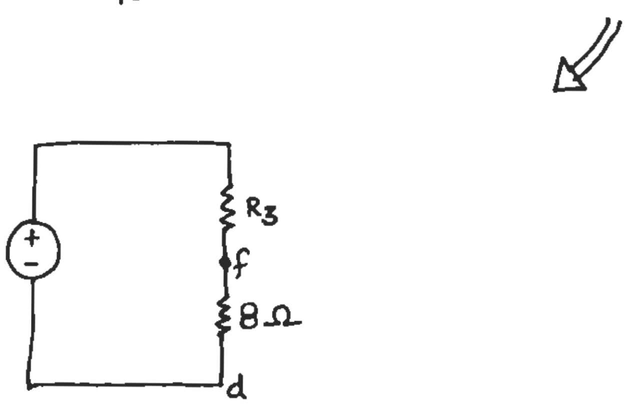
Figure P2.61

Solution: 2.61



$R_1 = 9 + 8 + 9 = 26\,\Omega$

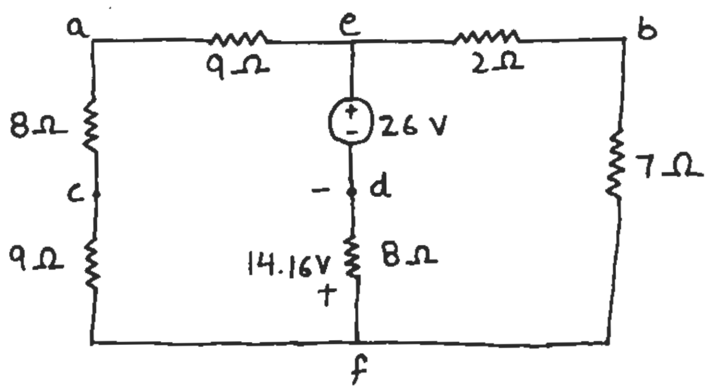
$R_2 = 2 + 7 = 9\,\Omega$



$R_3 = R_1 \parallel R_2 = 6.69\,\Omega$

$V_{fd} = 26\left[\dfrac{8}{R_3 + 8}\right] = 14.16\text{ V}$

Now we have



$$V_{ef} = (26 - 14.16) = 11.84 \text{ V}$$

$$V_{ea} = V_{ef}\left[\frac{9}{9+8+9}\right] = 4.098 \text{ V}$$

$$V_{eb} = V_{ef}\left[\frac{2}{2+7}\right] = 2.63 \text{ V}$$

$$V_{ab} = V_{ae} + V_{eb} = -4.098 + 2.63 = -1.468 \text{ V}$$

$$\boxed{V_{ab} = -1.47 \text{ V}}$$

$$V_{ef} = V_{ef}\left[\frac{9}{9+8+9}\right] = 4.098 \text{ V}$$

$$V_{de} = V_{df} + V_{fc} = -14.16 + (-4.098) = -18.26 \text{ V}$$

$$\boxed{V_{dc} = -18.3 \text{ V}}$$

2.62 Find V_1 and I_A in the network in Fig P2.62.

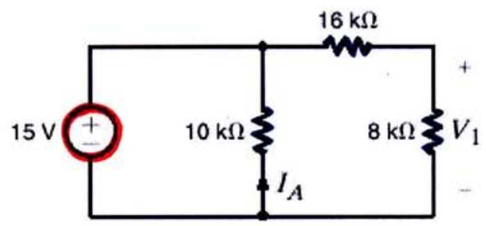
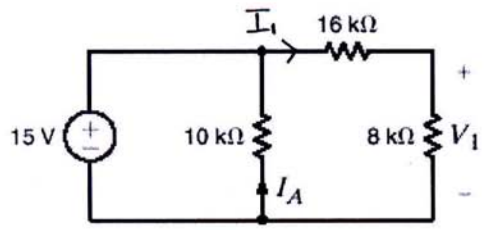


Figure P2.62

SOLUTION:



$$I_A = -\frac{15}{10K}$$

$$I_A = -1.5mA$$

$$I_1 = \frac{15}{16K+8K}$$

$$I_1 = 0.625\ mA$$

$$V_1 = I_1(8K) = (0.625m)(8K)$$

$$V_1 = 5V$$

2.63 Find I_o in the network in Fig P2.63.

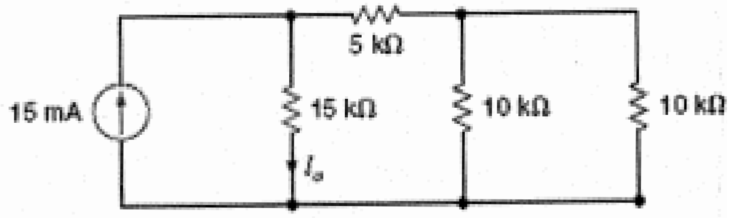
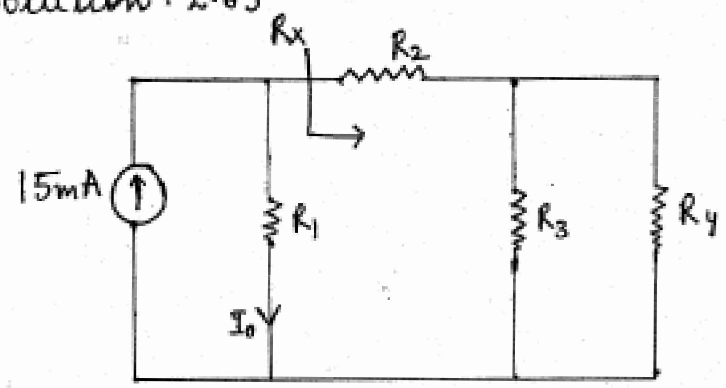


Figure P2.63

Solution: 2.63



$R_1 = 15\,k\Omega$, $R_2 = 5\,k\Omega$, $R_3 = 10\,k\Omega$, $R_4 = 10\,k\Omega$

$R_X = R_2 + (R_3 \parallel R_4) = 10\,k\Omega$

$$I_0 = 15 \times 10^{-3} \left[\frac{R_X}{R_1 + R_X} \right]$$

$$\boxed{I_0 = 6\,mA}$$

2.64 Determine I_o in the circuit in Fig. P2.64.

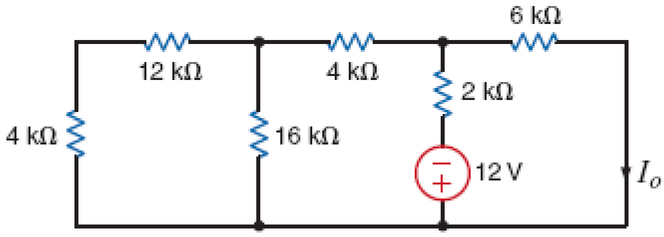
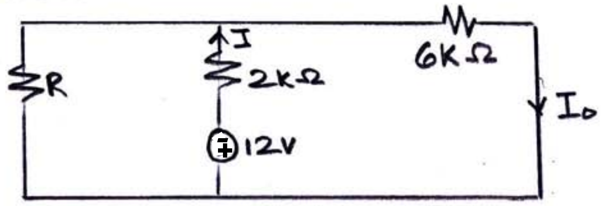


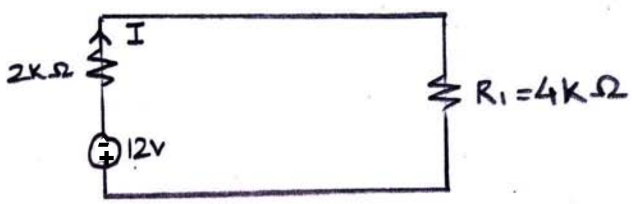
Figure P2.64

SOLUTION:



$$R = [(4K + 12K) \| 16K] + 4K$$

$$R = 8K + 4K = 12K\,\Omega$$



$R_1 = 12K \| 6K$

$R_1 = 4K\,\Omega$

$$I = \frac{-12}{2K + 4K} = -2mA$$

Current divison:

$$I_o = \left(\frac{12k}{12k + 6k}\right)(-2m)$$

$$I_o = -1.33\,mA$$

2.65 Find V_1 in the network in Fig P2.65.

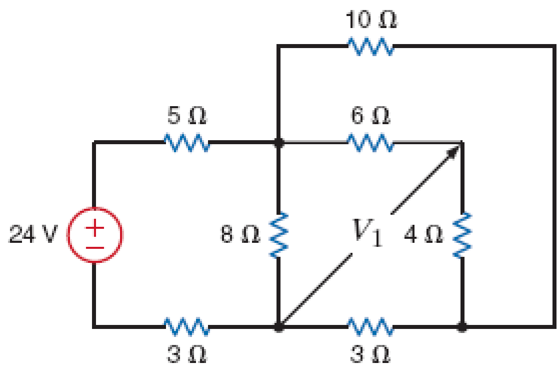
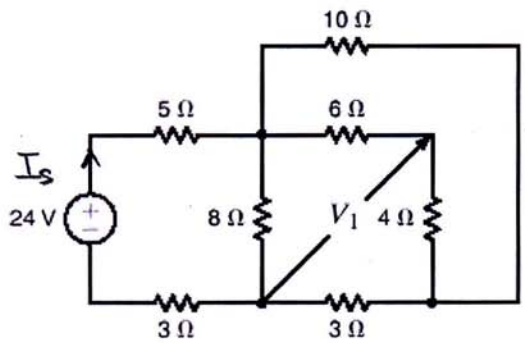


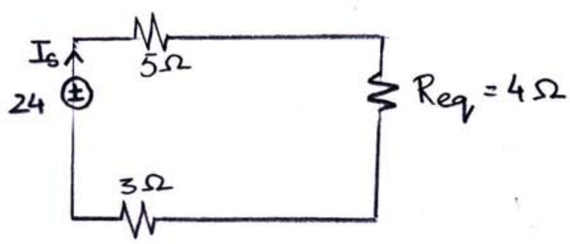
Figure P2.65

SOLUTION:

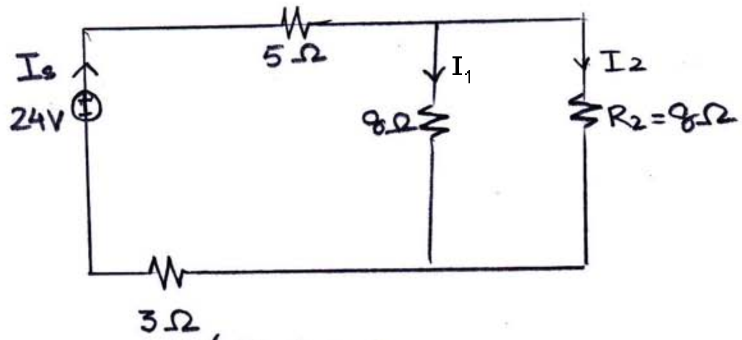


$$R_{eq} = \{[10 \| (6+4)] + 3\} \| 8$$

$$R_{eq} = (5+3) \| 8 = 4\Omega$$



$$I_s = \frac{24}{5+4+3} = 2A$$

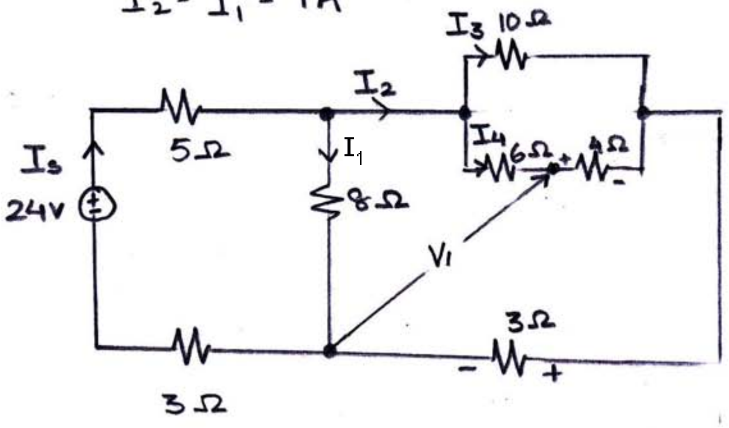


$R_2 = [10 \| (6+4)] + 3$

$R_2 = 8\Omega$

$I_1 = \left(\frac{8}{8+8}\right)(2) = 1A$

$I_2 = I_1 = 1A$



$I_3 = \left(\frac{6+4}{6+4+10}\right) I_2$

$I_3 = 0.5A$

$I_4 = I_3 = 0.5A$

KVL:

$V_1 = I_4(4) + I_2(3)$

$V_1 = 0.5(4) + (1)(3)$

$V_1 = 5V$

2.66 Determine V_o in the network in Fig. P2.66.

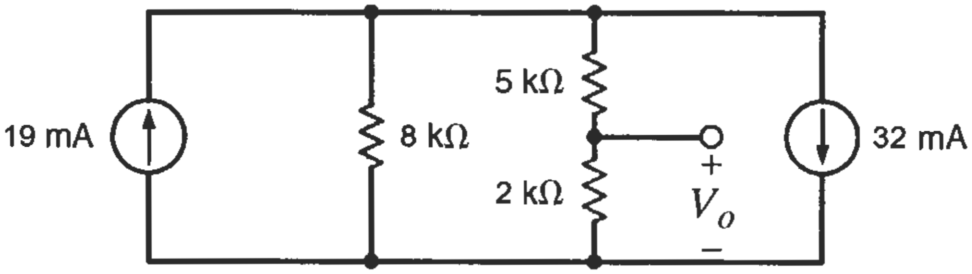
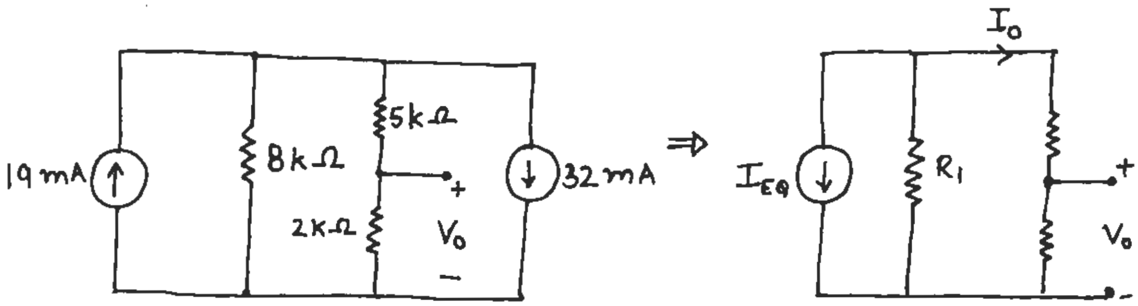


Figure P2.66

Solution: 2.66



$R_1 = 8\,k\Omega$, $R_2 = 5\,k\Omega$, $R_3 = 2\,k\Omega$

$$I_{EQ} = (32 - 19) = 13 \text{ mA}$$

$$-I_o = I_{EQ}\left[\frac{R_1}{R_1 + (R_2 + R_3)}\right] \Rightarrow I_o = -6.93 \text{ mA}$$

$$V_o = I_o R_3$$
$$= -13.86 \text{ V}$$

$$\boxed{V_o = -13.9 \text{ V}}$$

2.67 Find V_{ab} in the circuit in Fig P2.67.

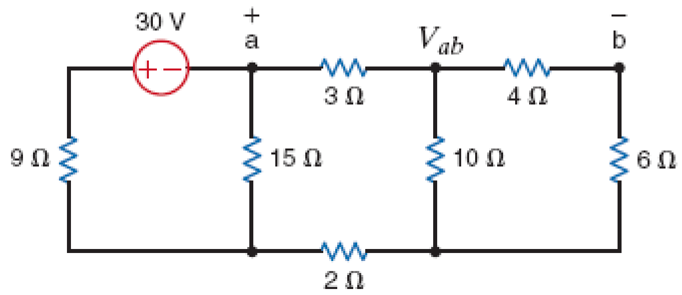
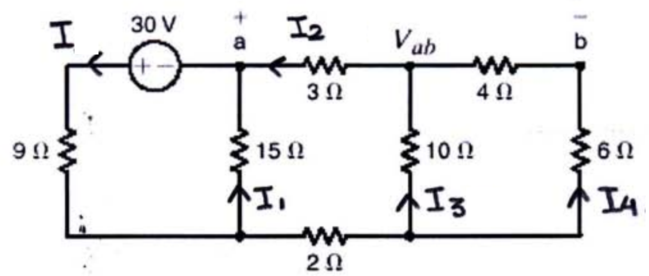


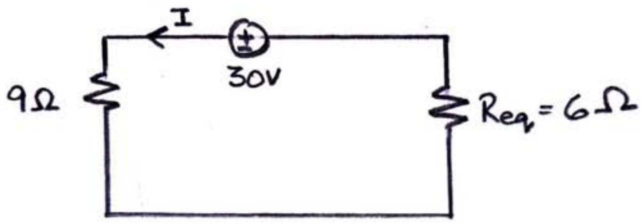
Figure P2.67

SOLUTION:



$$R_{eq} = \{[(4+6) \| 10] + 3+2\} \| 15$$

$$R_{eq} = (5+5) \| 15 = 6\,\Omega$$



$$I = \frac{30}{9+6} = 2A$$

KVL around orignal circuit:

$$30 = 9I + 15I_1$$

$$15I_1 = 12$$

$$I_1 = \frac{4}{5}\text{A}$$

KCL:

$$I = I_1 + I_2$$

$$I_2 = 2 - \frac{4}{5}$$

$$I_2 = \frac{6}{5}\text{A}$$

$$I_4 = \left(\frac{10}{10+4+6}\right)(I_2)$$

$$I_4 = \frac{3}{5}\text{A}$$

KVL:

$$V_{ab} + 3I_2 + 4I_4 = 0$$

$$V_{ab} = -3\left(\frac{6}{5}\right) - 4\left(\frac{3}{5}\right)$$

$$V_{ab} = -6\text{V}$$

2.68 Find V_{ab} in the network in Fig P2.68.

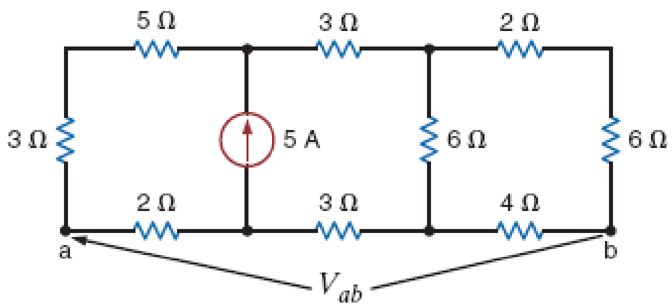
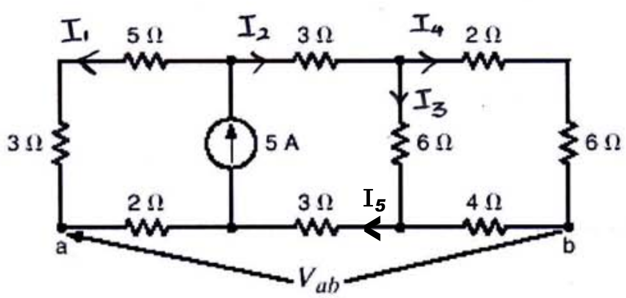


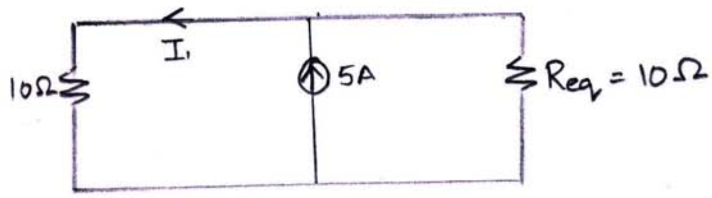
Figure P2.68

SOLUTION:



$$R_{eq} = (2+6+4\|6)+6$$

$$R_{eq} = 10\,\Omega$$



$$I_1 = \left(\frac{10}{10+10}\right)(5) = 2.5\text{A}$$

$$I_2 = I_1 = 2.5\text{A}$$

$$I_4 = \left(\frac{6}{6+2+6+4}\right)(I_2)$$

$$I_4 = 0.833\text{A}$$

$$I_5 = 2.5A$$

$$I_3 = I_5 - I_4$$

$$I_3 = 2.5 - 0.833$$

$$I_3 = 1.67\,A$$

KVL:

$$2I_1 = 3I_5 + 4I_4 + V_{ab}$$

$$V_{ab} = 2(2.5) - 3(2.5) - 4(0.833)$$

$$V_{ab} = -5.83V$$

2.69 Find I_1, I_2 and V_1 in the circuit in Fig P2.69.

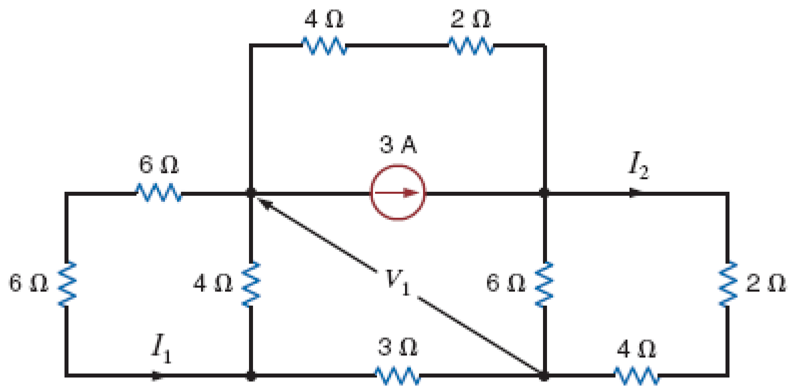
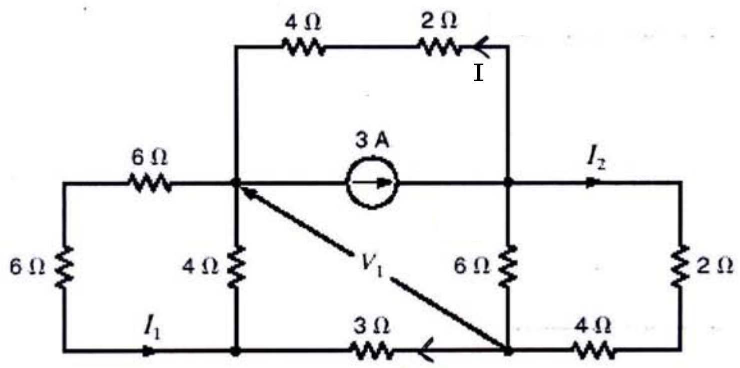
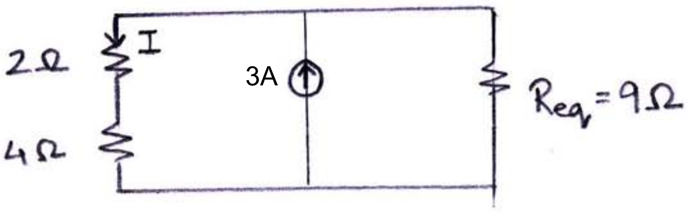


Figure P2.69

SOLUTION:



$$R_1 = [(2+4)\|6] + 3 + [(6+6)\|4] = 3+3+3 = 9\,\Omega$$



$$I = \left(\frac{9}{9+2+4}\right)(3) = 1.8\text{ A}$$

$$I_2 = \left(\frac{6}{6+2+4}\right)(3-I)$$

$$I_2 = 0.6\text{ A}$$

$$I_1 = \left(\frac{4}{4+6+6}\right)(-3+I)$$

$$I_1 = -0.3A$$

KVL:

$$2I + 4I + V_1 = 2I_2 + 4I_2$$

$$V_1 = 6I_2 - 6I$$

$$V_1 = 6(0.6) - 6(1.8)$$

$$V_1 = -7.2V$$

2.70 If $V_o = 4$ V in the network in Fig. P2.70, find V_S.

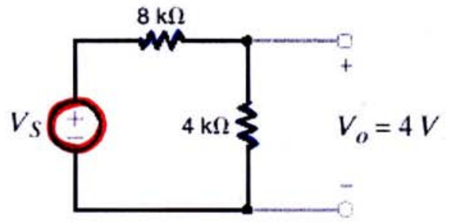


Figure P2.70

SOLUTION:

$$V_o = \left(\frac{4K}{4K+8K}\right) V_S$$

$$V_S = \frac{4}{\left(\frac{4K}{4K+8K}\right)} = 12V$$

2.71 If the power absorbed by the 4−kΩ resistor in the circuit in Fig. P2.71 is 36 mW, find V_S.

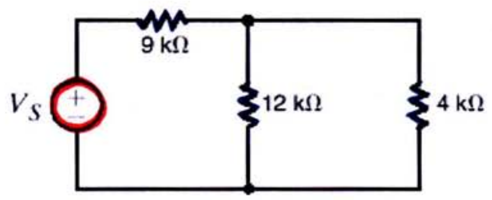
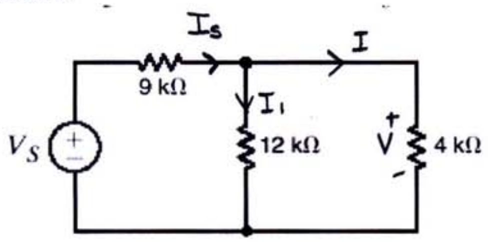


Figure P2.71

SOLUTION:



$$P_{4k} = 36\,mW$$

$$P_{4k} = \frac{V^2}{R} \qquad P_{4k} = I^2 R$$

$$V = \sqrt{P_{4k} R} \qquad I = \sqrt{\frac{P_{4k}}{R}}$$

$$V = 12V \qquad I = \sqrt{\frac{36m}{4K}} = 3mA$$

$$I_1 = \frac{V}{12k} = \frac{12}{12K}$$

$$I_1 = 1mA$$

KCL:

$$I_s = I_1 + I$$

$$I_s = 1m + 3m$$

$I_s = 4mA$

KVL:

$V_s = I_s(9K) + V$

$V_s = 4m(9K) + 12$

$V_s = 48V$

2.72 If $I_o = 5$ mA in the circuit in Fig. P2.72, find I_S.

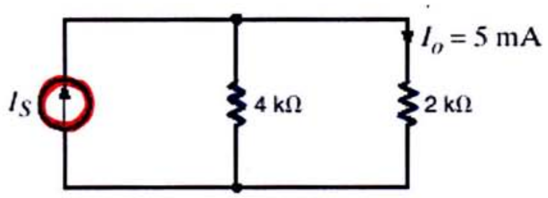
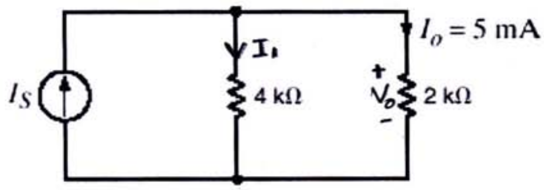


Figure P2.72

SOLUTION:



$$V_o = I_o(2k) = 5m(2k) = 10V$$

$$I_1 = \frac{10}{4k}$$

$$I_1 = 2.5mA$$

KCL:

$$I_s = I_1 + I_o$$

$$I_s = 2.5m + 5m$$

$$I_s = 7.5mA$$

2.73 If $I_o = 2$ mA in the circuit in Fig. P2.73., find V_S.

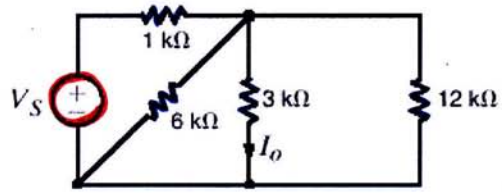
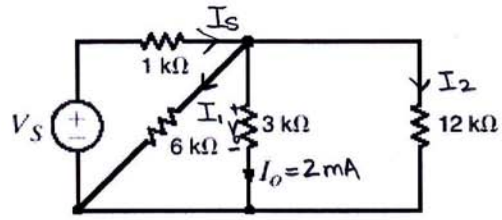


Figure P2.73

SOLUTION:



$$V_O = I_o(3K) = 2m(3K) = 6V$$

$$I_1 = \frac{6}{6K} = 1mA$$

$$I_2 = \frac{6}{12K} = 0.5mA$$

KCL:

$$I_S = I_1 + I_o + I_2 = 1m + 2m + 0.5m$$

$$I_S = 3.5mA$$

KVL:

$$V_S = 1K I_S + V_o$$

$$V_S = 1K(3.5) + 6$$

$$V_S = 9.5\ V$$

2.74 Find the value of V_s in the network in Fig. P2.74 such that the power supplied by the current source is 0.

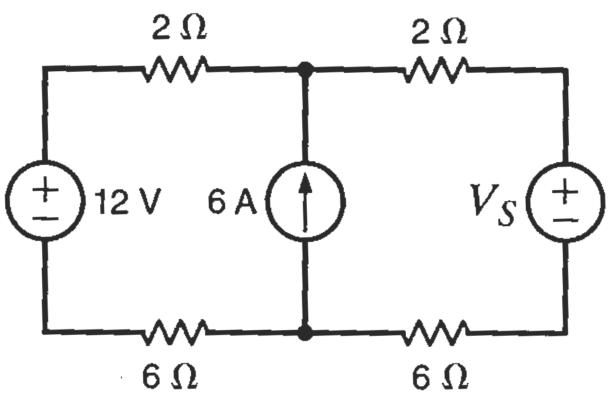
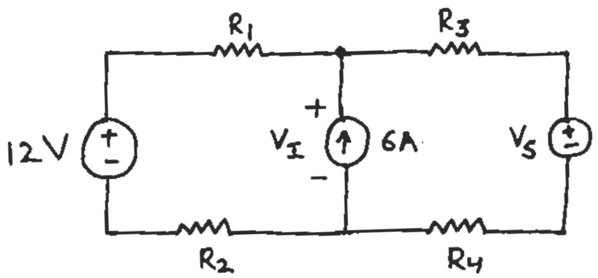


Figure P2.74

Solution: 2.74



$R_1 = 2\,\Omega,\quad R_2 = 6\,\Omega,\quad R_3 = 2\,\Omega,\quad R_4 = 6\,\Omega$

$P_{I_s} = 6\,V_I = 0 \Rightarrow V_I = 0$

KCL :
$$\frac{12}{R_1+R_2} + \frac{V_s}{R_3+R_4} + 6 = 0$$

$$\frac{12}{8} + \frac{V_s}{8} + 6 = 0$$

$$\boxed{V_s = -60.0 \text{ V}}$$

2.75 In the network in Fig. P2.75. $V_1 = 12$ V. Find V_S.

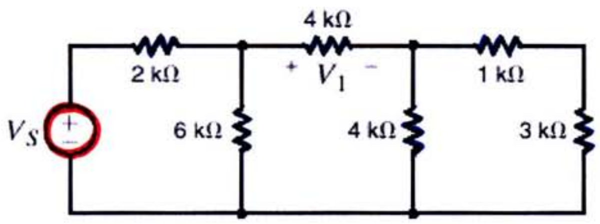
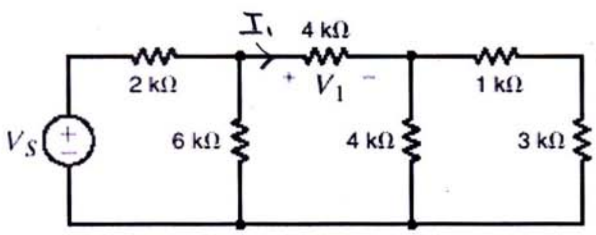
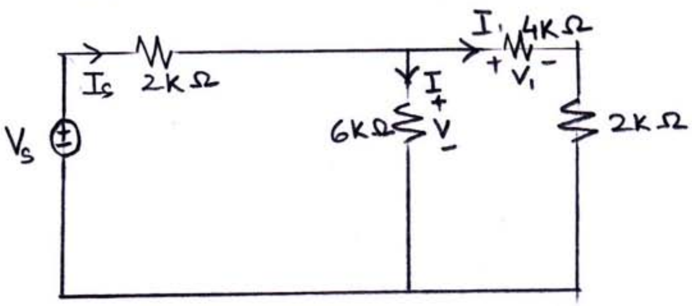


Figure P2.75

SOLUTION:



$$I_1 = \frac{V_1}{4k} = \frac{12}{4k} = 3mA$$



$R_2 = (1K + 3K) \| 4K$

$R_2 = 2K\Omega$

$$V = I_1(4K + 2K) = 3m(6K) = 18V$$

$$I = \frac{V}{6K} = \frac{18}{6K} = 3mA$$

KCL:

$$I_S = I + I_1 = 3m + 3m = 6mA$$

KVL:

$$V_S = I_S(2k) + V$$

$$V_S = 6m(2k) + 18$$

$$V_S = 30V$$

2.76 In the network in Fig. P2.76, $V_o = 8$V. Find I_s.

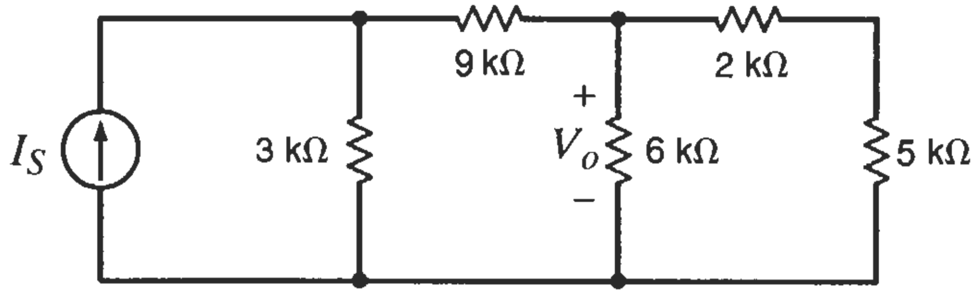
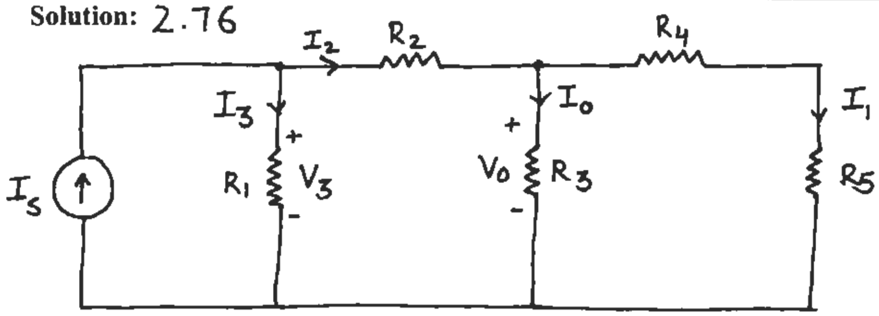


Figure P2.76

Solution: 2.76



$R_1 = 3\,k\Omega,\ R_2 = 9\,k\Omega,\ R_3 = 6\,k\Omega,\ R_4 = 2\,k\Omega,\ R_5 = 5\,k\Omega$

$I_o = V_o/R_3 = 8/6 = 1.33\ mA$

$I_1 = \dfrac{V_o}{R_4 + R_5} = \dfrac{8}{7} = 1.143\ mA$

$I_2 = I_o + I_1 = (1.33 + 1.143)\,mA = 2.473\,mA$

$V_3 = I_2R_2 + V_o = (2.473 \times 9) + 8 = 30.257\ V$

$I_3 = \dfrac{V_3}{R_1} = 10.087\ mA$

$I_s = I_2 + I_3 = 2.473 + 10.087 = 12.56\,mA$

$\boxed{I_s = 12.6\ mA}$

2.77 In the circuit in Fig. P2.77, $V_o = 2$ V. Find I_S.

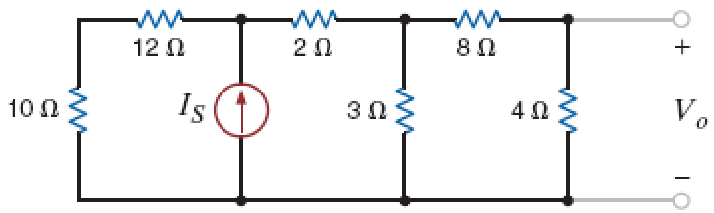
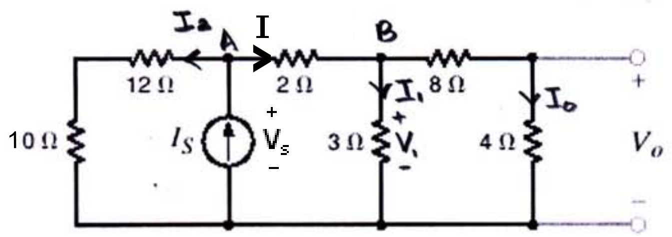


Figure P2.77

SOLUTION:



$$I_o = \frac{V_o}{4} = \frac{2}{4} = 0.5\text{A}$$

$$V_1 = I_o(12) = 0.5(12) = 6\text{V}$$

$$I_1 = \frac{V_1}{3} = \frac{6}{3} = 2\text{A}$$

KCL at B:

$$I = I_1 + I_o$$

$$I = 2 + 0.5 = 2.5\text{A}$$

KVL :

$$V_s = I(2) + V_1$$

$$V_s = 2.5(2) + 6$$

$$V_s = 11\text{V}$$

$$I_2 = \frac{V_s}{10+12} = \frac{11}{22} = 0.5A$$

KCL at A:

$$I_s = I + I_2 = 2.5 + 0.5$$

$$I_s = 3A$$

2.78 Find the value of V_1 in the network in Fig. P2.78 such that $V_a = 0$.

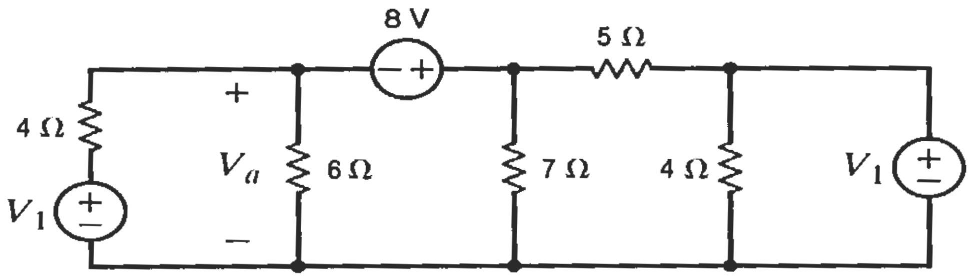
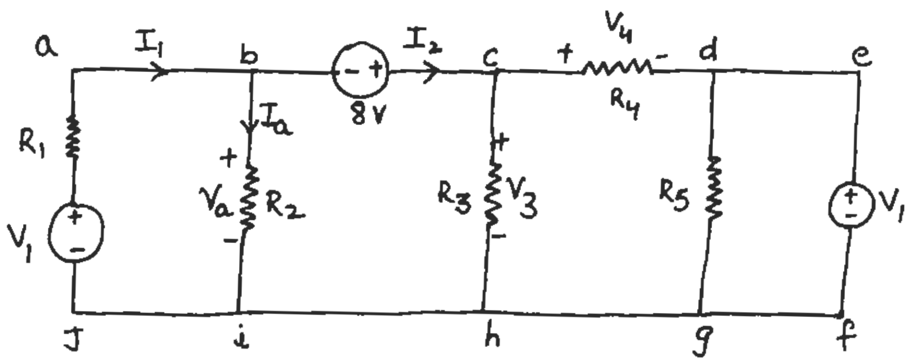


Figure P2.78

Solution: 2.78



$R_1 = 4\,\Omega$, $R_2 = 6\,\Omega$, $R_3 = 7\,\Omega$, $R_4 = 5\,\Omega$, $R_5 = 4\,\Omega$

$I_1 = I_a + I_2 \Rightarrow I_1 = I_2$ (By Ohm's law, if $V_a = 0$, $I_a = 0$)

$$I_1 = \frac{V_1}{R_1} = \frac{V_1}{4}$$

$$I_2 = \frac{V_3}{R_3} + \frac{V_4}{R_4} = \frac{V_3}{7} + \frac{V_4}{5}$$

Applying KVL in loop bchib

$$8 + 0 - V_3 = 0$$

$$V_3 = 8\text{ V}$$

Applying KVL in loop cdefghc

$$-V_3 + V_4 + V_1 = 0$$

$$V_4 = 8 - V_1$$

So, $I_2 = \frac{8}{7} + \frac{8 - V_1}{5}$

$I_1 = I_2 = \frac{8}{7} + \frac{8 - V_1}{5}$

So, $\frac{V_1}{4} = \frac{8}{7} + \frac{8 - V_1}{5}$

$V_1 = 6.095 \text{ V}$

$\boxed{V_1 = 6.10 \text{ V}}$

2.79 If $V_1 = 3V$ in the circuit in Fig. P2.79, find I_S.

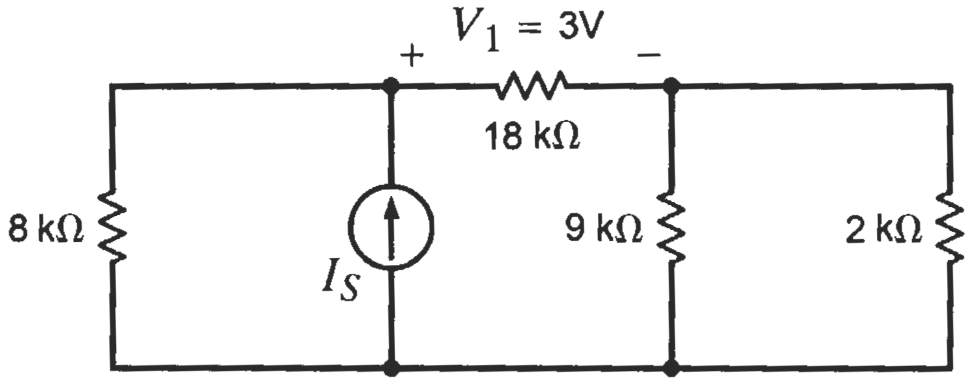
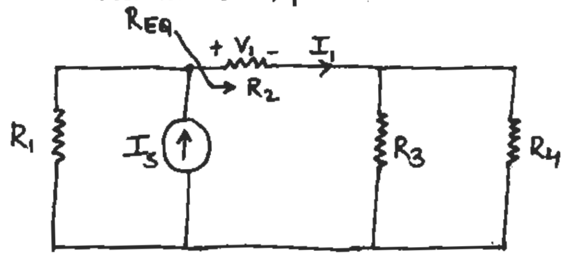


Figure P2.79

Solution: 2.79



$R_1 = 8\,k\Omega,\ R_2 = 18\,k\Omega,\ R_3 = 9\,k\Omega,\ R_4 = 2\,k\Omega$

$V_1 = 3V$

$R_{EQ} = R_2 + (R_3 \| R_4) = 19.636 = 19.64\,k\Omega$

$$I_1 = \frac{V_1}{R_2} = \frac{3}{18} = \frac{1}{6}\,mA$$

$$I_1 = I_S\left[\frac{R_1}{R_1 + R_{EQ}}\right]$$

$$\boxed{I_S = 0.576\ mA}$$

2.80 In the network in Fig. P2.80, $V_1 = 16$ V. Find V_S.

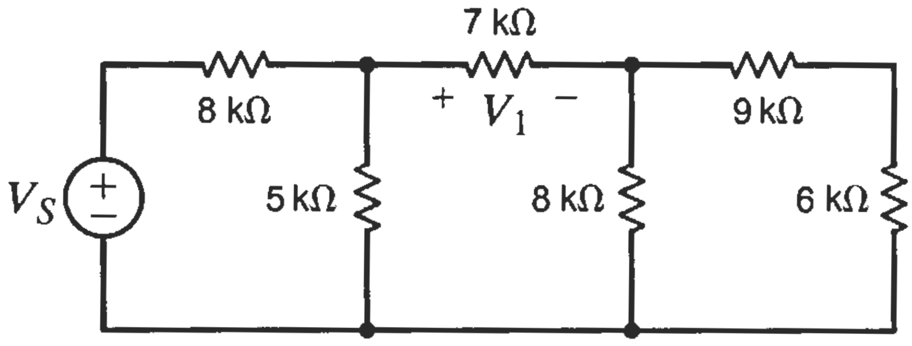
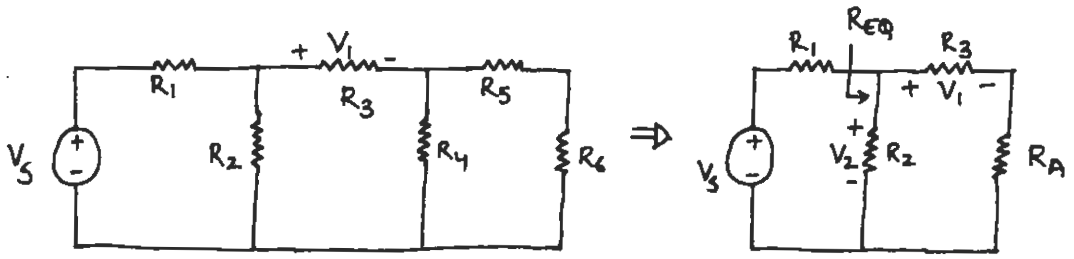


Figure P2.80

Solution: 2.80



$V_1 = 16$ V, $R_1 = 8$ kΩ, $R_2 = 5$ kΩ, $R_3 = 7$ kΩ, $R_4 = 8$ kΩ, $R_5 = 9$ kΩ, $R_6 = 6$ kΩ

$$R_A = R_4 \parallel (R_5 + R_6) = 5.217 \text{ k}\Omega$$

$$R_{EQ} = R_2 \parallel (R_3 + R_A) = 3.548 \text{ k}\Omega$$

$$V_1 = V_2 \left[\frac{R_3}{R_3 + R_A}\right] \Rightarrow V_2 = 27.925 \text{ V}$$

$$V_2 = V_S \left[\frac{R_{EQ}}{R_{EQ} + R_1}\right] \Rightarrow V_S = 90.89 \text{ V}$$

$$\boxed{V_S = 90.9 \text{ V}}$$

2.81 Given that $V_o = 4$ V in the network in Fig. P2.81, find V_S.

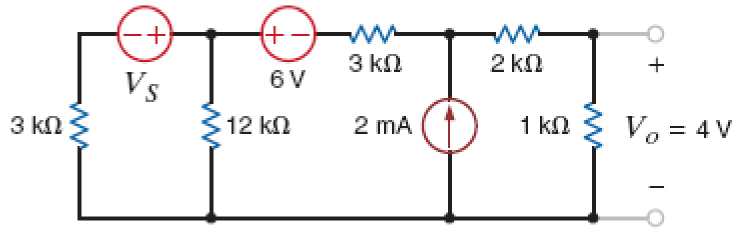
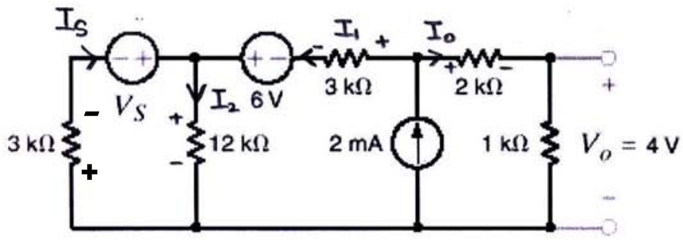


Figure P2.81

SOLUTION:



$$I_o = \frac{V_o}{1k} = \frac{4}{1k} = 4mA$$

$$I_1 + I_o = 2m$$

$$I_1 = 2m - 4m$$

$$I_1 = -2mA$$

KVL:

$$4 + I_o(2k) + 6 = I_1(3k) + I_2(12k)$$

$$(12k)I_2 = 4 + 4m(2k) + 6 - (-2m)(3k)$$

$$I_2 = 2mA$$

KCL:

$$I_s + I_1 = I_2$$

$$I_s = I_2 - I_1$$

$$I_s = 2m - (-2m)$$

$$I_s = 4mA$$

KVL:

$$V_s = 3K I_s + 12K I_2$$

$$V_s = 3K(4m) + 12K(2m)$$

$$V_s = 36V$$

2.82 Given that $I_x = 4$ A, find R, V_{ab}, and the power supplied by the 10-A current source in the network in Fig. P2.82.

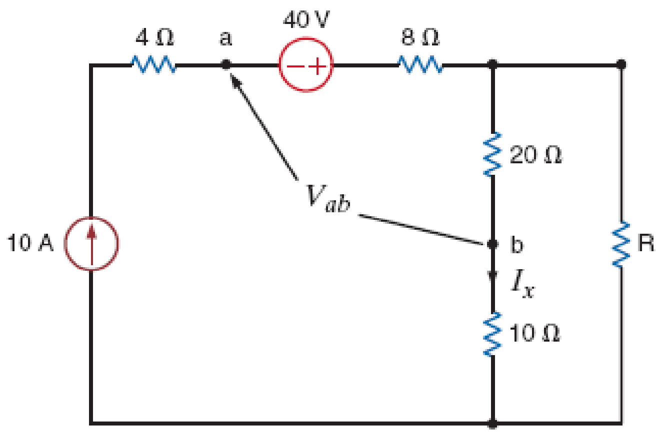
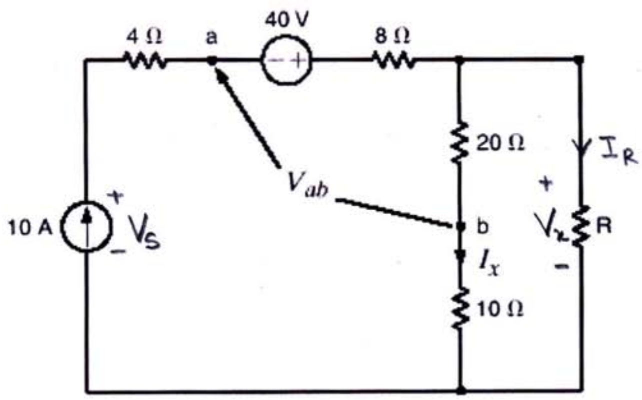


Figure P2.82

SOLUTION:



$$V_x = I_x(20+10) = 4(20+10)$$

$$V_x = 120V$$

KCL:

$$10 = I_x + I_R$$

$$I_R = 10 - 4$$

$$I_R = 6A$$

$V_x = I_R R$

$R = \frac{V_x}{I_R}$

$R = \frac{120}{6}$

$R = 20\Omega$

KVL:

$V_{ab} + 40 = 10(8) + I_x(20)$

$V_{ab} = 80 - 40 + (4)(20)$

$V_{ab} = 120\text{V}$

KVL:

$V_s + 40 = 10(4) + 10(8) + I_R R$

$V_s = -40 + 40 + 80 + 6(20)$

$V_s = 200\text{V}$

$P_{10A} = V_s(10) = 200(10)$

$P_{10A} = 2\text{KW}$

2.83 Find, the value of V_x in the network in Fig. P2.83 such that the 8-A current source supplies 48 W.

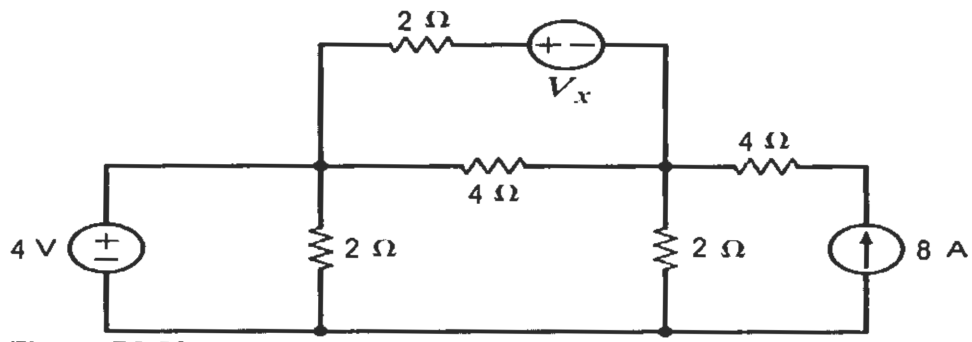
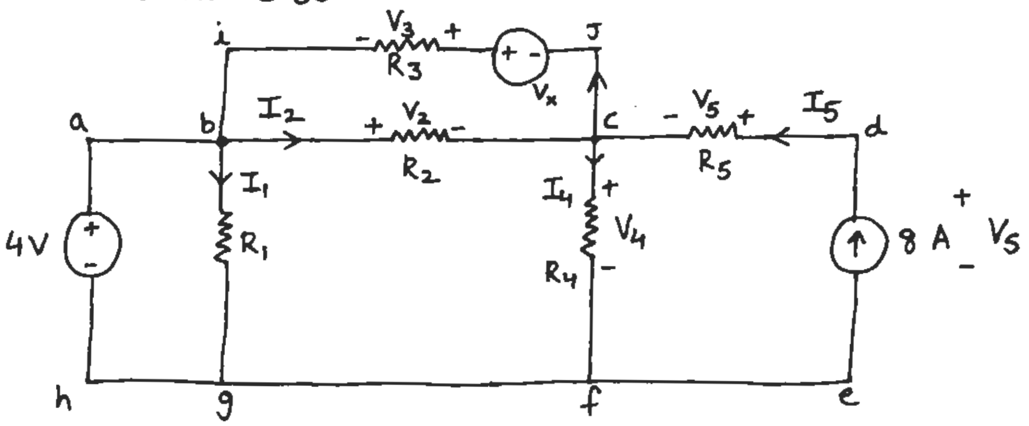


Figure P2.83

Solution: 2.83



$R_1 = 2\,\Omega,\ R_2 = 4\,\Omega,\ R_3 = 2\,\Omega,\ R_4 = 2\,\Omega,\ R_5 = 4\,\Omega$

$P_{8A} = (V_s)(8) = 48 \Rightarrow V_s = 6\text{ V}$

$V_5 = R_5 I_5 = 32\text{ V}$

$V_s = V_5 + V_4 \Rightarrow V_4 = -V_5 + V_s \Rightarrow V_4 = -26\text{ V}$

$I_4 = \dfrac{V_4}{R_4} = -13\text{ A}$

KVL for loop abcfgha

$-4 + V_2 + V_4 = 0$

$V_2 = 4 - V_4 = 30\text{ V}$

$I_2 = \dfrac{V_2}{R_2} = 7.5\text{ A}$

KCL at node c:

$$I_2 + I_5 = I_3 + I_4$$

$$\therefore I_3 = I_2 + I_5 - I_4$$

$$= 7.5 + 8 + 13$$

$$I_3 = 28.5 \text{ A}$$

$$V_3 = R_3 I_3 = 57 \text{ V}$$

$$V_x = V_3 + V_2$$

$$= 57 + 30$$

$$= 87 \text{ V}$$

$$\boxed{V_x = 87 \text{ V}}$$

2.84 If the power absorbed by the 6-A current source in the circuit in Fig. P2.84 is 144 W, find V_S and the power supplied by the 24-V voltage source.

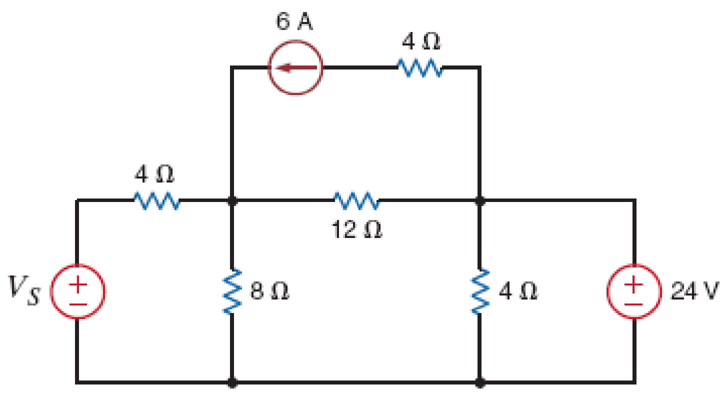
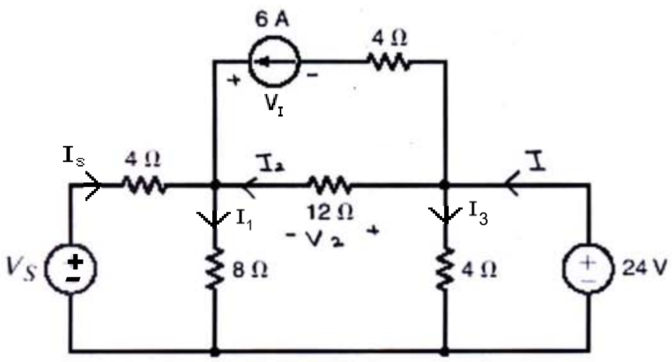


Figure P2.84

SOLUTION:



$$P_{6A} = V_I(6)$$

$$V_I = \frac{P_6 A}{6} = \frac{144}{6} = 24\,V$$

$$V_I = 24\,V$$

$$V_I - 6A(4) = I_2(12)$$

$$I_2(12) = 0$$

$$I_2 = 0A$$

KVL:

$$24 + V_I = 6(4) + 8I_1$$

$$8I_1 = 24 + 24 - 24$$

$$I_1 = 3A$$

KCL:

$$I_s + 6 = I_1$$

$$I_s = 3 - 6$$

$$I_s = -3A$$

KVL:

$$V_s = I_s(4) + I_1(8)$$

$$V_s = -3(4) + (3)(8)$$

$$V_s = 12V$$

KVL:

$$V_2 + V_I = 4(6)$$

$$V_2 = 0V$$

$$V_2 = I_2(12)$$

$$I_2 = 0A$$

$$I_3 = \frac{24}{4} = 6A$$

KCL:

$$I = I_3 + I_2 + 6$$

$$I = 6 + 0 + 6$$

$$I = 12A$$

$$P_{24V} = 24(I) = 24(12)$$

$$P_{24V} = 288\ W$$

2.85 Given I_0 = 8mA in the circuit in Fig. P2.85, find I_A.

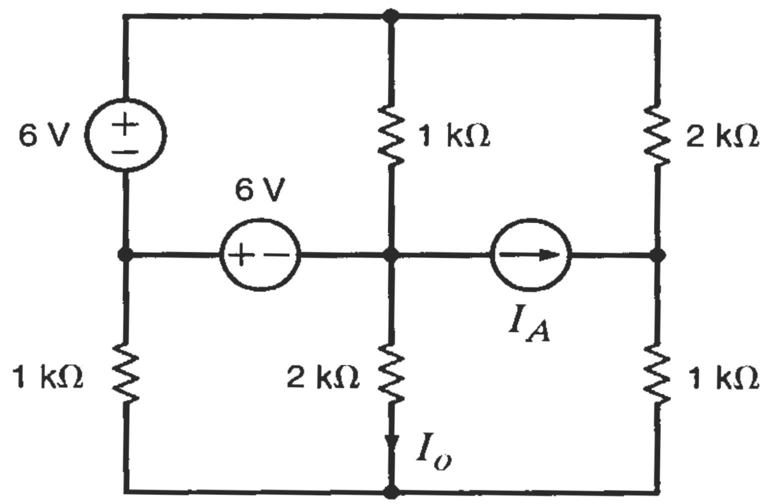
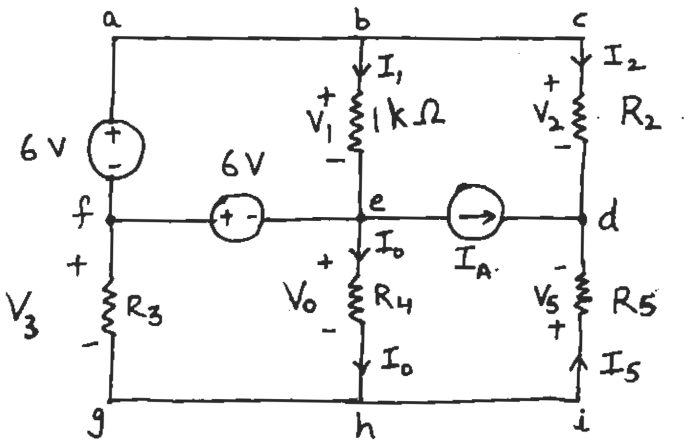


Figure P2.85

Solution: 2.85



$R_1 = 1\,k\Omega,\ R_2 = 2\,k\Omega,\ R_3 = 1\,k\Omega,\ R_4 = 2\,k\Omega,\ R_5 = 1\,k\Omega$

$V_o = R_4 I_o = 16\ V$

$V_3 = 6 + V_o = 22V$

$I_3 = V_3/R_3 = 22\ mA$

$I_5 = I_3 + I_o = 30\ mA$

$$V_1 = 6 + 6 = 12\text{ V}$$

$$I_1 = \frac{V_1}{R_1} = 12\text{ mA}$$

KVL for the loop abcdihgfa

$$V_2 = 6 + I_3 R_3 + I_5 R_5$$
$$V_2 = 58\text{ V}$$

$$I_2 = \frac{V_2}{R_2} = 29\text{ mA}$$

$$I_A = -I_2 - I_5$$

$$\Rightarrow \boxed{I_A = -59\text{ mA}}$$

2.86 Given $I_o = 2$ mA in the network in Fig. P2.86, find V_A.

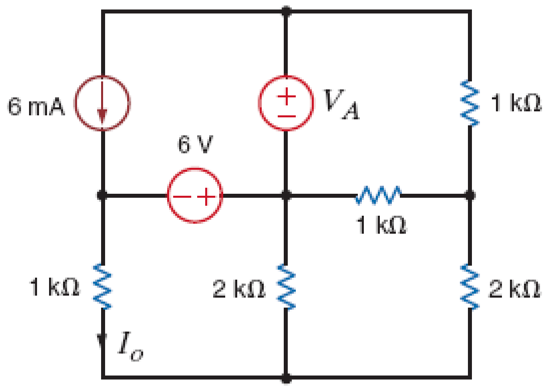
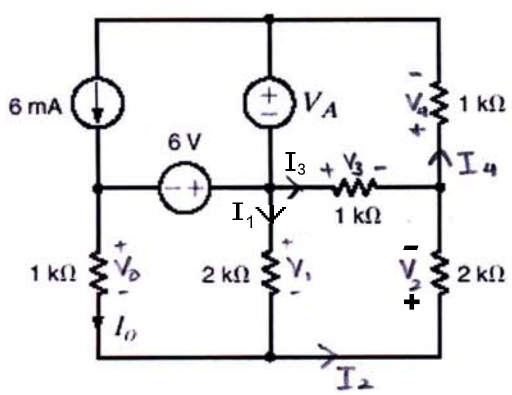


Figure P2.86

SOLUTION:



$$V_o = I_o(1k) = 2m(1k) = 2V$$

KVL:

$$V_1 = V_o + 6 \qquad I_1 = \frac{V_1}{2k}$$

$$V_1 = 2 + 6 = 8V \qquad I_1 = \frac{8}{2k} = 4mA$$

KCL:

$$I_o + I_1 = I_2$$

$$I_2 = 2m + 4m = 6mA$$

$V_2 = I_2(2K) = 6m(2k) = 12V$

KVL:

$V_1 + V_2 = V_3$

$V_3 = 8 + 12 = 20V$

$I_3 = \frac{V_3}{1K} = \frac{20}{1K} = 20mA$

KCL:

$I_2 + I_3 = I_4$

$I_4 = 6m + 20m = 26mA$

$V_4 = I_4(1K) = 26m(1K) = 26V$

KVL:

$V_A + V_4 + V_3 = 0$

$V_A = -26 - 20$

$V_A = -46V$

2.87 Given V_o in the network in Fig. P2.87, find I_A.

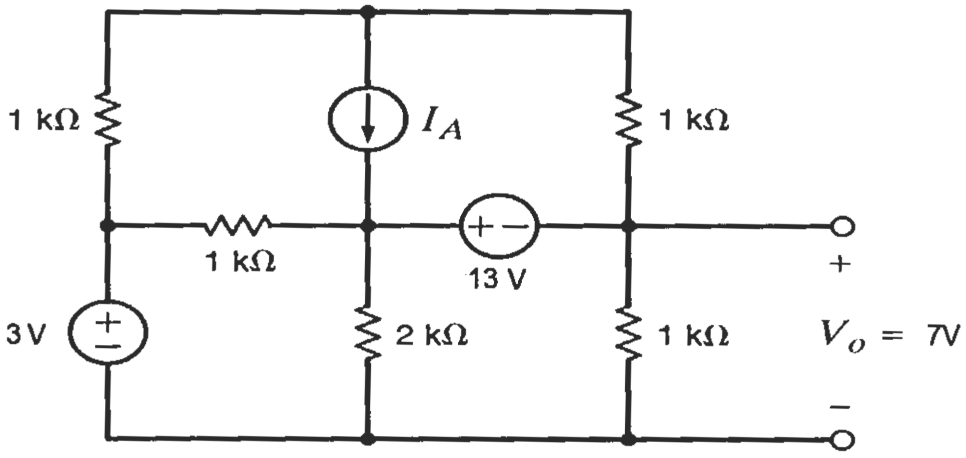
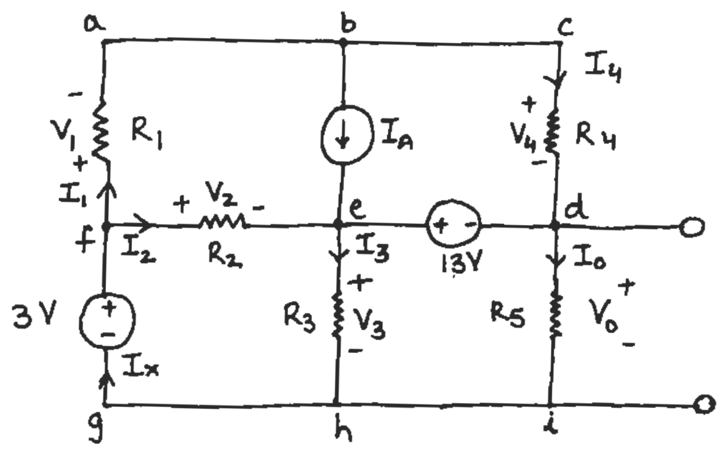


Figure P2.87

Solution: 2.87



$R_1 = 1\,k\Omega$, $R_2 = 1\,k\Omega$, $R_3 = 2\,k\Omega$, $R_4 = 1\,k\Omega$, $R_5 = 1\,k\Omega$

$V_o = 7\,V$

$$I_o = V_o / R_5 = 7\,mA$$

$$V_3 = 13 + V_o = 20\,V$$

$$I_3 = V_3 / R_3 = 10\,mA$$

$$I_x = I_3 + I_o = 17\,mA$$

$$V_2 = 3 - V_3 = -17\text{ V}$$

$$I_2 = V_2/R_2 = -17\text{ mA}$$

$$I_1 = I_x - I_2 = 34\text{ mA}$$

$$V_1 = R_1 I_1 = 34\text{ V}$$

KVL for the loop abcdihgfa

$$\Rightarrow V_4 + V_0 + V_1 = 3$$

$$V_4 = 3 - V_0 - V_1$$

$$= -38\text{ V}$$

$$I_4 = V_4/R_4 = -38\text{ mA}$$

$$I_A + I_4 = I_1$$

So, $I_A = I_1 - I_4$

$$= 72\text{ mA}$$

$$\boxed{I_A = 72\text{ mA}}$$

2.88 If the power supplied by the 2-A current source is 40 W, find V_S and the power absorbed by the 5-V source in the network in Fig. P2.88.

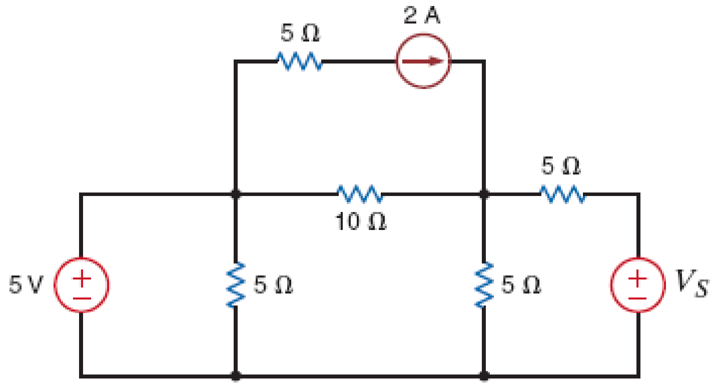
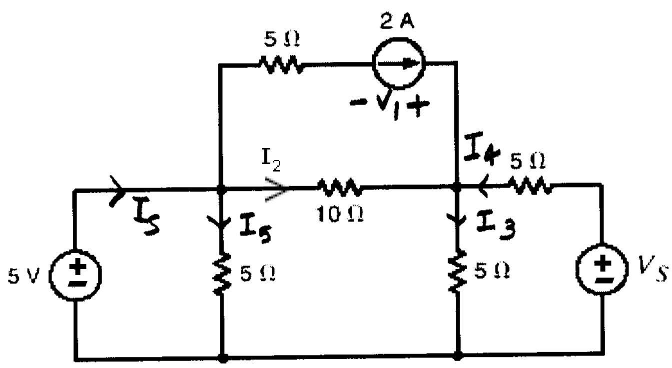


Figure P2.88

SOLUTION:



$$P_{2A} = V_1(2)$$

$$V_1 = \frac{P_{2A}}{2} = \frac{40}{2}$$

$$V_1 = 20\text{V}$$

KVL: $10I_2 + V_1 = 5(2)$

$$I_2 = -1\text{A}$$

KVL: $5 + V_1 = 5(2) + I_3(5)$

$$5I_3 = 5 + 20 - 10$$

$$I_3 = 3\text{A}$$

KCL: $2 + I_2 + I_4 = I_3$

$$2 - 1 + I_4 = 3$$

$$I_4 = 2A$$

KVL: $V_s = 5I_4 + 5I_3$

$$V_s = 5(2) + 5(3)$$

$$V_s = 25V$$

KCL:

$$I_s = I_2 + I_5 + 2$$

$$I_5 = \frac{5}{5} = 1A$$

$$I_s = -1 + 1 + 2$$

$$I_s = 2A$$

$$P_{5V} = I_s(5) = 2(5)$$

$$P_{5V} = 10W$$

2.89 The 40-V source in the circuit in Fig. P2.89 is absorbing 80 W of power. Find V_x.

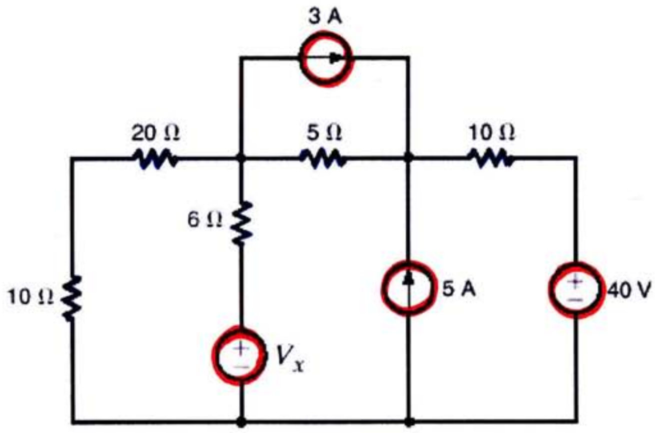
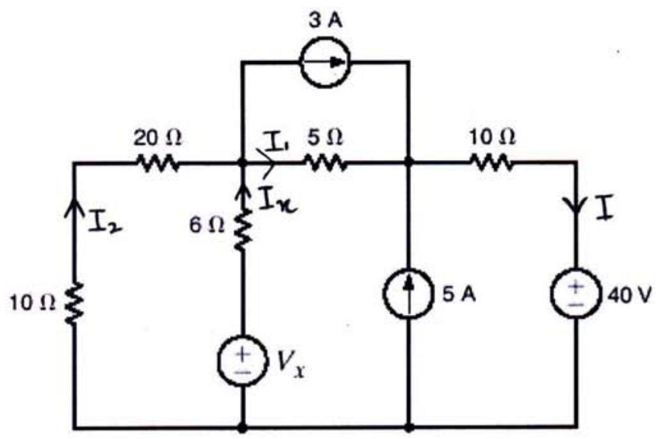


Figure P2.89

SOLUTION:



$$P_{40} = 40(I)$$

$$I = \frac{80}{40} = 2A$$

KCL:

$$I_1 + 3 + 5 = I$$

$$I_1 = 2 - 3 - 5$$

$$I_1 = -6A$$

KVL:

$$10I_2 + 20I_2 + 5I_1 + 10I + 40 = 0$$

$$30I_2 = -40 - 5I_1 - 10I$$

$$30I_2 = -40 - 5(-6) - 10(2)$$

$$I_2 = -1A$$

KCL: $I_2 + I_x = I_1 + 3$

$$I_x = -6 + 3 - (-1)$$

$$I_x = -2A$$

KVL:

$$V_x = 6I_x + 5I_1 + 10I + 40$$

$$V_x = 6(-2) + 5(-6) + 10(2) + 40$$

$$V_x = 18V$$

2.90 Find the value of V_X in the circuit in Fig. P2.90 such that the power supplied by the 6-A source is 54 W.

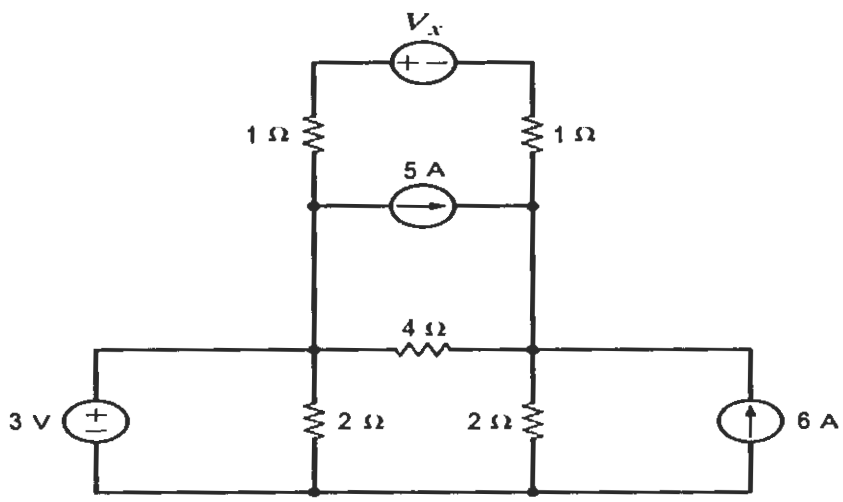
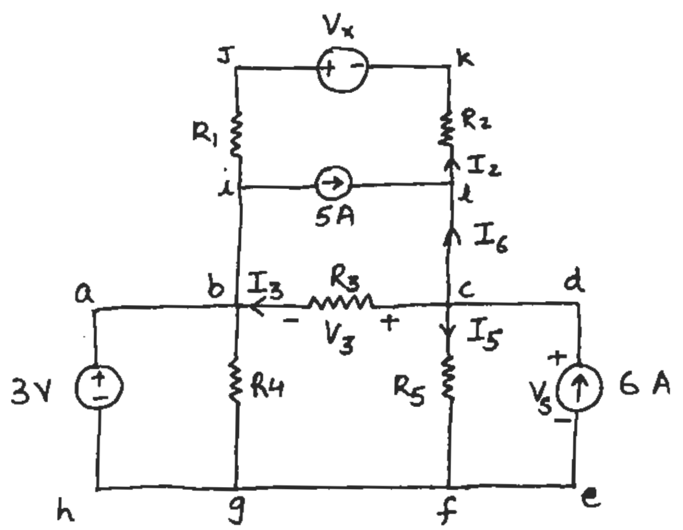


Figure P2.90

Solution: 2.90



$R_1 = 1\,\Omega$, $R_2 = 1\,\Omega$, $R_3 = 4\,\Omega$, $R_4 = 2\,\Omega$, $R_5 = 2\,\Omega$

$$P_{6A} = 54 = 6V_s \Rightarrow V_s = 9\text{ V}$$

$$I_5 = \frac{V_s}{R_5} = 4.5\text{ A}$$

KVL for loop abcdefgha

$V_3 = V_S - 3 = 6\ V$

$I_3 = V_3 / R_3 = 1.5\ A$

KCL at C:

$I_6 + I_3 + I_5 = 6$

$I_6 = 6 - I_3 - I_5 = 0$

KCL at l:

$I_2 = I_6 + 5 = 5mA$

KVL for loop bijklcb

$V_3 + V_X = I_2 R_2 + I_2 R_1$

$V_X = I_2 R_2 + I_2 R_1 - V_3$

$\boxed{V_X = 4\ V}$

2.91 Given that $V_1 = 4$ V, find V_A and R_B in the circuit in Fig. P2.91.

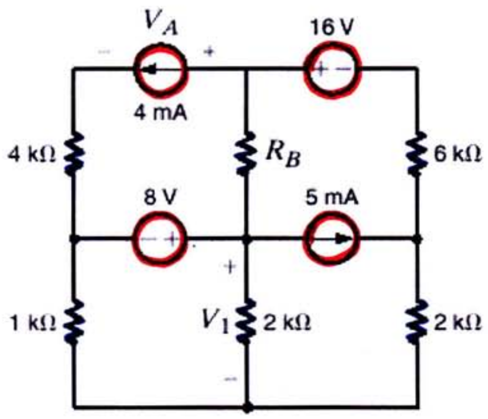
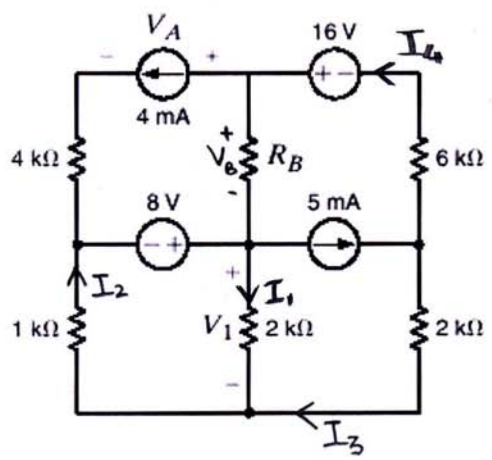


Figure P2.91

SOLUTION:



$$V_1 = I_1(2K)$$

$$I_1 = \frac{4}{2K} = 2mA$$

KVL:

$$V_1 + 1K I_2 = 8$$

$$I_2 = \frac{8-4}{1K} = 4mA$$

KCL:

$$I_1 + I_3 = I_2$$

$$I_3 = 4m - 2m$$

$$I_3 = 2mA$$

KCL:

$$I_3 + I_4 = 5mA$$

$$I_4 = 3mA$$

KCL:

$$I_4 = I_B + 4m$$

$$I_B = -1mA$$

KVL:

$$2K I_3 + 16 = 6K I_4 + V_B + V_1$$

$$V_B = 2K(2m) + 16 - 6K(3m) - 4$$

$$V_B = -2V$$

$$V_B = I_B R_B$$

$$R_B = \frac{-2}{-1m} = 2K\Omega$$

KVL:

$$8 + V_B = V_A + 4k(4m)$$

$$V_A = 8 - 2 - 4k(4m)$$

$$V_A = -10\,V$$

2.92 Find the power absorbed by the network in Fig. P2.92.

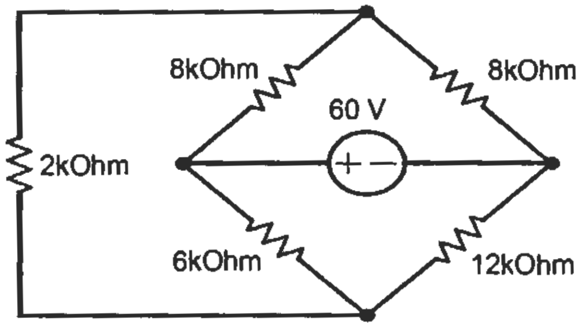
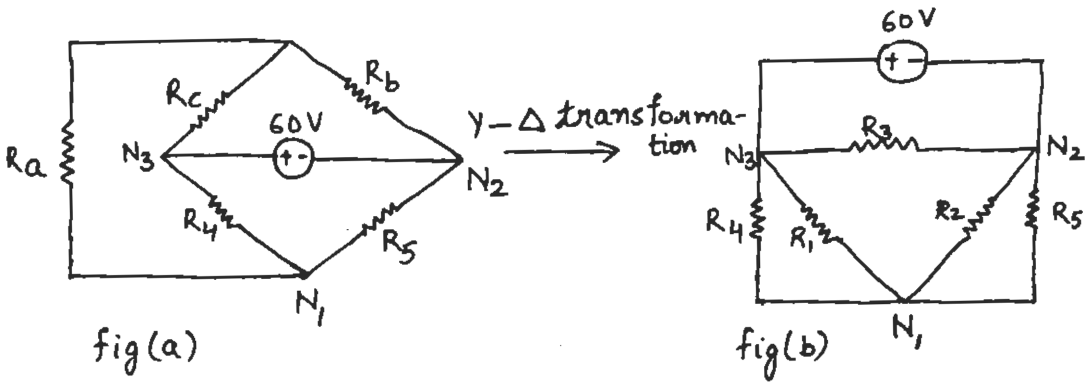


Figure P2.92

Solution: 2.92



R_a, R_b, R_c connected in wye configuration

$R_a = 2\,k\Omega$, $R_b = 8\,k\Omega$, $R_c = 8\,k\Omega$, $R_4 = 6\,k\Omega$,

$R_5 = 12\,k\Omega$

$$R_1 = \frac{R_a R_b + R_b R_c + R_a R_c}{R_b} = 12\,k\Omega$$

$$R_2 = \frac{R_a R_b + R_b R_c + R_a R_c}{R_c} = 12\,k\Omega$$

$$R_3 = \frac{R_a R_b + R_b R_c + R_a R_c}{R_a} = 48\,k\Omega$$

fig (b) $\rightarrow$ fig (c)

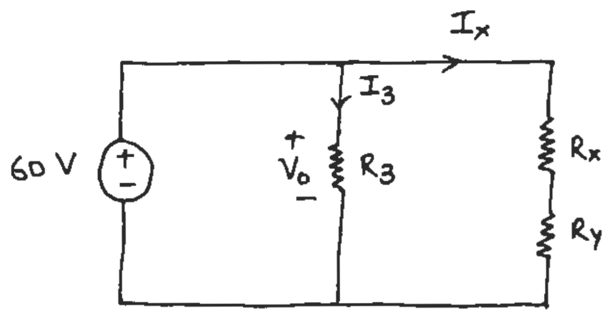


fig (c)

$$R_x = R_1 \,||\, R_4 = 4\text{ k}\Omega$$

$$R_y = R_2 \,||\, R_5 = 6\text{ k}\Omega$$

$$P = \frac{V_o^2}{R_3} + \frac{V_o^2}{R_x + R_y}$$

$$\boxed{P = 435\text{ mW}}$$

2.93 Find the value of g in the network in Fig. P2.93 such that the power supplied by the 3-A source is 20 W.

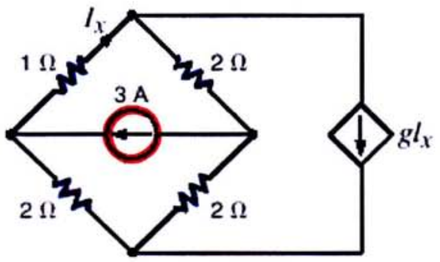
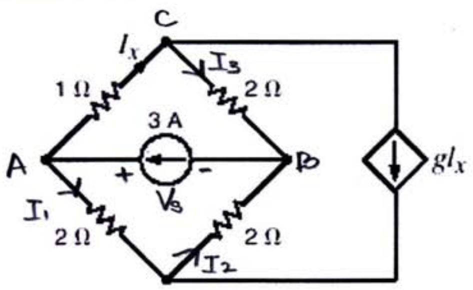


Figure P2.93

SOLUTION:



$$P = V_s I_s$$

$$20 = V_s (3)$$

$$V_s = \frac{20}{3} \text{ V}$$

KVL:

$$V_s = I_x + 2I_3 \quad — ①$$

KCL at A:

$$3 = I_1 + I_x$$ Putting eqⁿ ① for I_x

$$I_x = 3 - I_1$$

$$V_s = \underbrace{3 - I_1}_{I_2} + 2I_3$$

$$\frac{20}{3} - 3 = -I_1 + 2I_3$$

$$\boxed{11 = -3I_1 + 6I_3}$$

KVL:

$$V_s = 2I_1 + 2I_2$$

KCL at B:

$$3 = I_2 + I_3$$

$$I_2 = 3 - I_3$$

$$\frac{20}{3} = 2I_1 + 2(3 - I_3)$$

$$\boxed{2 = 6I_1 - 6I_3}$$

$$-3I_1 + 6I_3 = 11$$

$$6I - 6I_3 = 2$$

$$I_1 = 4.33\text{A}$$

$$I_3 = 4\text{A}$$

$I_x = 3 - I_1$

$I_x = 3 - 4.33$

$I_x = -1.33A$

KCL at C:

$I_x = I_3 + gI_x$

$-1.33 = 4 + g(-1.33)$

$g = 4$

2.94 Find I_o in the circuit in Fig. P2.94.

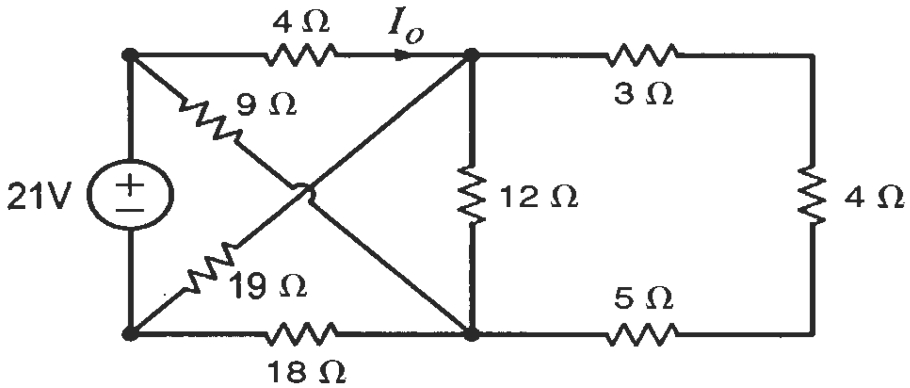


Figure P2.94

Solution: 2.94

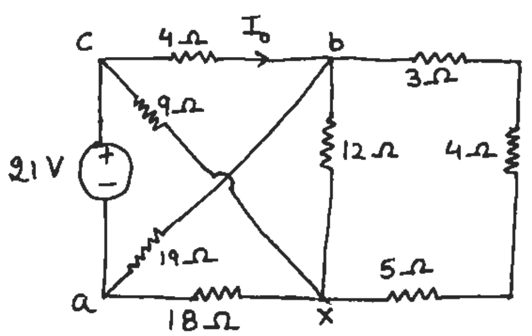


fig (a)

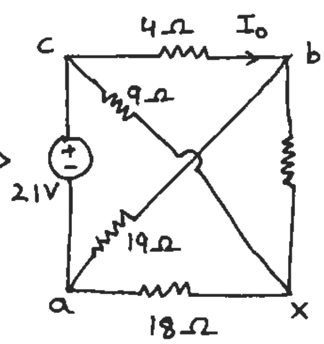
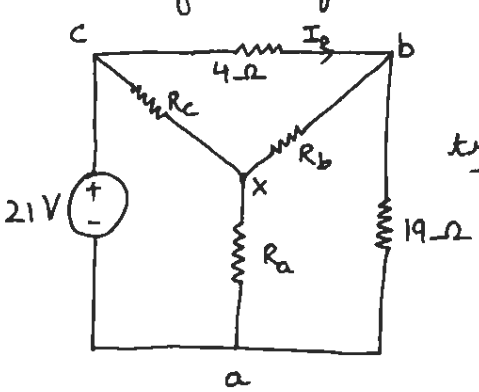


fig (b)

$$R_x = 12 \parallel (3+4+5) = 6\ \Omega$$

In fig (b) 18Ω, 9Ω, R_x are in wye connection

Therefore fig (b) is redrawn as fig (c)



wye-delta transformation

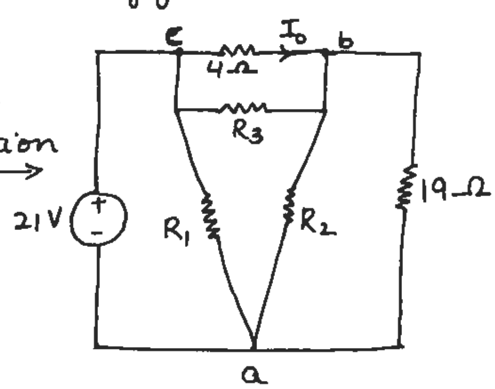


fig (c) fig (d)

In fig. (c) $R_a = 18\,\Omega$, $R_b = R_x = 6\,\Omega$, $R_c = 9\,\Omega$

From wye - delta transformation, we have

$$R_1 = \frac{R_a R_b + R_b R_c + R_a R_c}{R_b} = 54\,\Omega$$

$$R_2 = \frac{R_a R_b + R_b R_c + R_a R_c}{R_c} = 36\,\Omega$$

$$R_3 = \frac{R_a R_b + R_b R_c + R_a R_c}{R_a} = 18\,\Omega$$

fig (d) is transformed into fig (e)

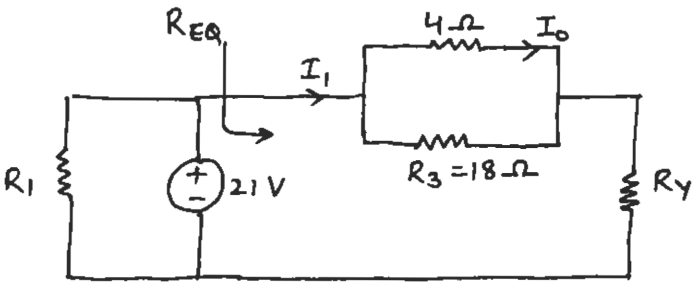


fig (e)

$$R_y = R_2 \parallel 19$$

$$R_y = 12.436\,\Omega$$

$$R_{EQ} = 4 \parallel R_3 + R_y$$

$$= 4 \parallel 18 + 12.436$$

$$R_{EQ} = 15.709\,\Omega$$

$$I_1 = \frac{21}{R_{EQ}} = 1.337\text{ A}$$

$$I_o = I_1 \left[\frac{18}{18+4}\right] = 1.09\text{ A}$$

$$\boxed{I_o = 1.09\text{ A}}$$

2.95 Determine the value of V_o in the network in Fig. P2.95.

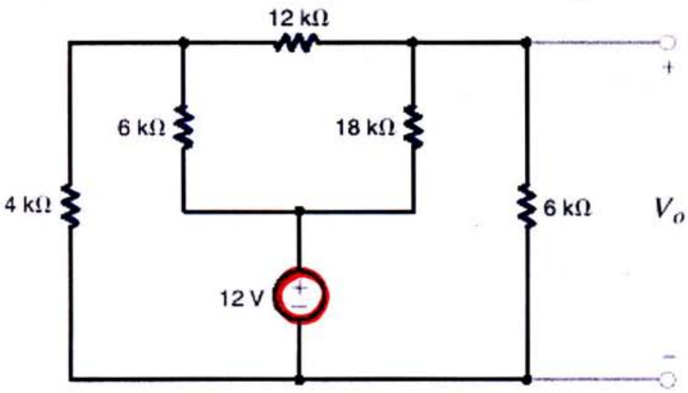
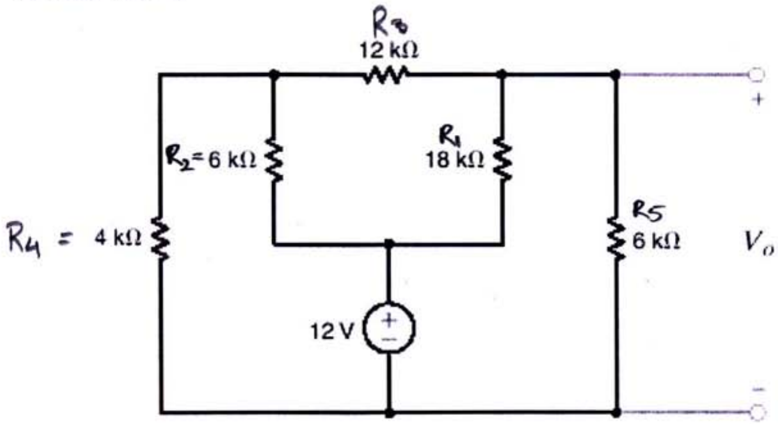


Figure P2.95

SOLUTION:

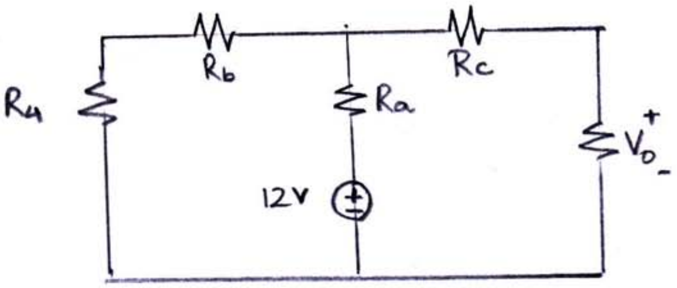


Using a delta to wye transformation:

$$R_a = \frac{R_1 R_2}{R_1 + R_2 + R_3} = \frac{18k(6k)}{18k + 6k + 12k} = 3k\,\Omega$$

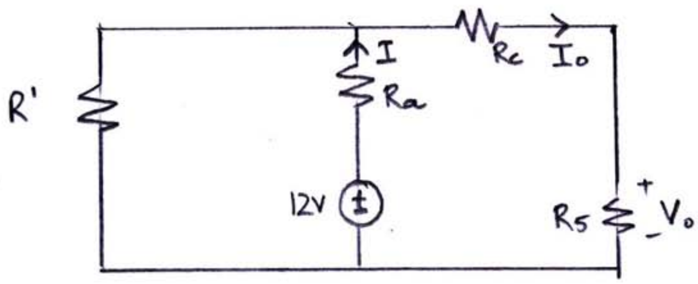
$$R_b = \frac{R_2 R_3}{R_1 + R_2 + R_3} = \frac{6k(12k)}{18k + 6k + 12k} = 2k\,\Omega$$

$$R_c = \frac{R_1 R_3}{R_1 + R_2 + R_3} = \frac{18k(12k)}{18k + 6k + 12k} = 6k\,\Omega$$



$$R' = R_4 + R_b = 4K + 2K$$

$$R' = 6K\ \Omega$$



$$R_{eq} = R' \| (R_c + R_5) = 6K \| (6K + 6K)$$

$$R_{eq} = 6K \| 12K = \frac{6K(12K)}{6K + 12K} = 4K\ \Omega$$

$$I = \frac{12}{R_a + R_{eq}} = \frac{12}{3K + 4K}$$

$$I = 1.714\ mA$$

Using current division:

$$I_o = \left(\frac{R'}{R' + R_c + R_5}\right)(I)$$

$$I_o = \left(\frac{6k}{6k+6k+6k}\right)(1.714m)$$

$$I_o = 0.571\,mA$$

$$V_o = I_o R_5 = (0.571m)(6k)$$

$$V_o = 3.43V$$

2.96 Find the power supplied by the 6-V source in the network in Fig. P2.96.

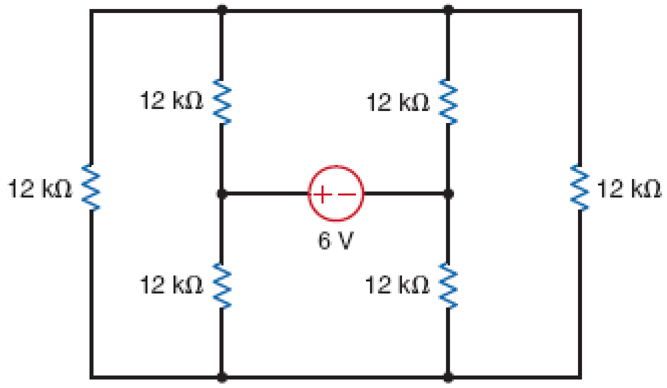
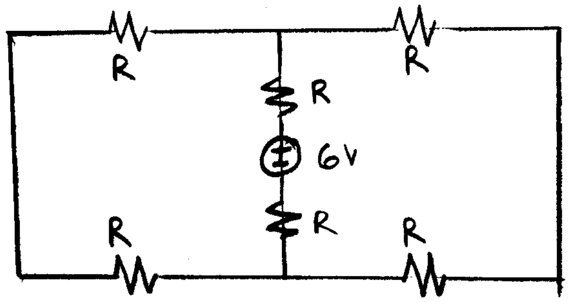


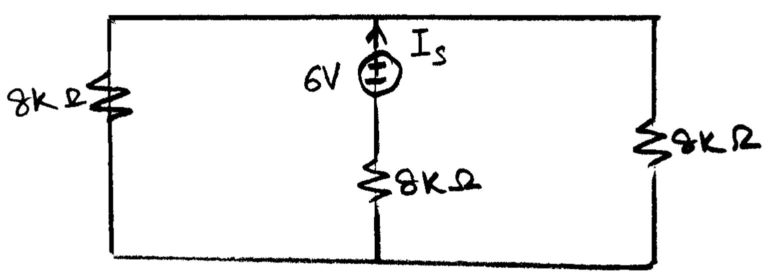
Figure P2.96

SOLUTION:

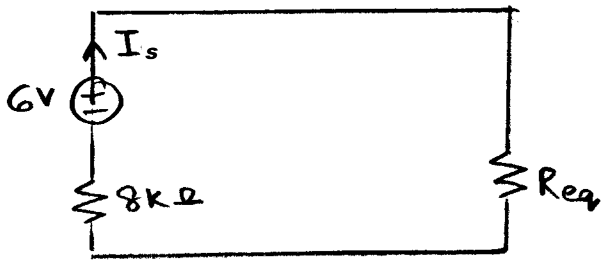
The three 12KΩ resistors on the left and the three on the right are connected in delta.

$$R = \frac{12K(12K)}{12K + 12K + 12K} = 4K\Omega$$





$$R_{eq} = (8K \| 8K) = 4K\,\Omega$$



$$I_s = \frac{6}{8K + R_{eq}} = \frac{6}{8K + 4k}$$

$$I_s = 0.5\,mA$$

$$P = V_s I_s = 6(0.5m)$$

$$P = 3mW$$

2.97 Find V_o in the circuit in Fig. P2.97.

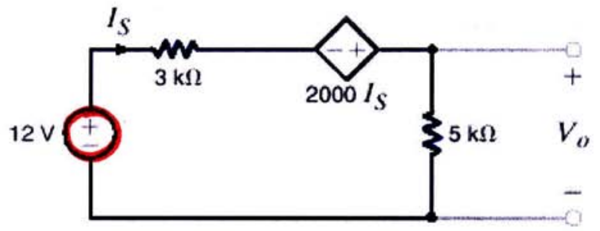


Figure P2.97

SOLUTION:

KVL:

$$12 + 2000 I_s = 3K I_s + 5K I_s$$

$$6K I_s = 12$$

$$I_s = 2mA$$

$$V_o = I_s (5K)$$

$$V_o = 2m(5K)$$

$$V_o = 10V$$

2.98 Find V_o in the network in Fig. P2.98.

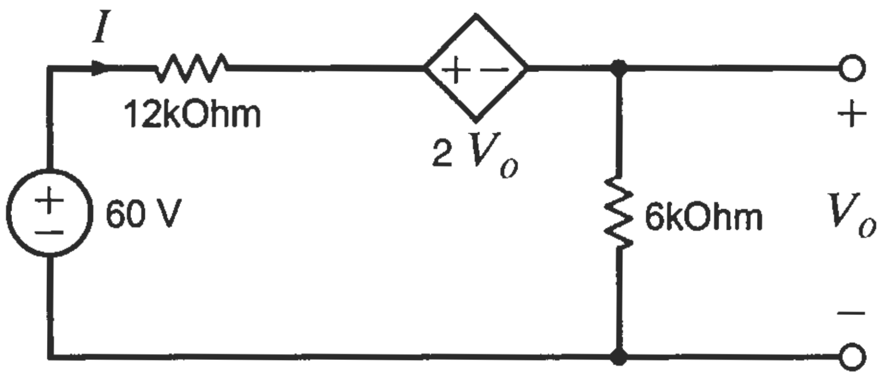
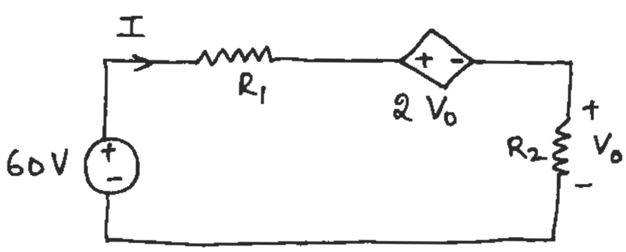


Figure P2.98

Solution: 2.98



$R_1 = 12\,k\Omega, \; R_2 = 6\,k\Omega$

$60 = R_1 I + 2V_o + R_2 I$

$V_o = R_2 I = 6 I$

$60 = 12I + 12I + 6I$

$I = 2\,A$

$$\boxed{V_o = 12\,V}$$

2.99 Find I_1 in the network in Fig. P2.99.

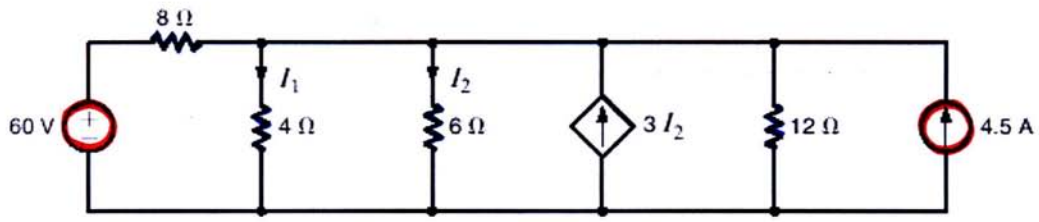
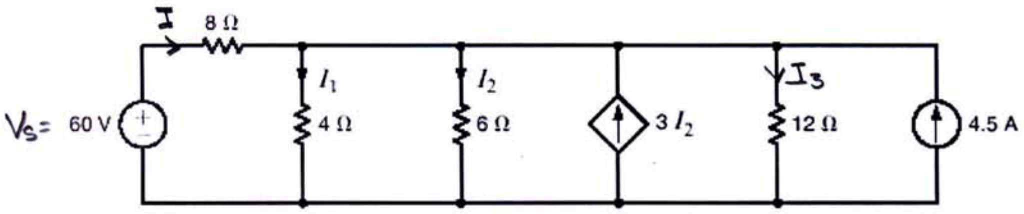


Figure P2.99

SOLUTION:



KCL:

$$I + 3I_2 + 4.5 = I_1 + I_2 + I_3$$

$$I = \frac{V_s - V_1}{8}$$

$$\frac{V_s - V_1}{8} + 3\left(\frac{V_1}{6}\right) + 4.5 = \frac{V_1}{4} + \frac{V_1}{6} + \frac{V_1}{12}$$

$$3(60) - 3V_1 + 12V + 108 = 6V_1 + 4V_1 + 2V_1$$

$$3V_1 = 288$$

$$V_1 = 96V$$

$$I_1 = \frac{V_1}{4} = \frac{96}{4} = 24A$$

2.100 Find I_1, I_2, and I_3 in the circuit in Fig. P2.100.

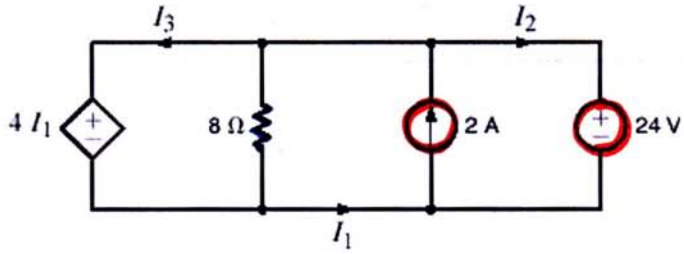
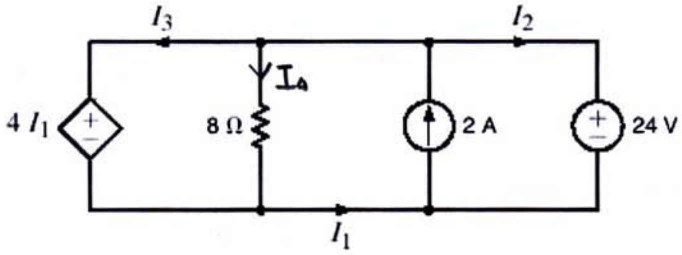


Figure P2.100

SOLUTION:



$$I_4 = \frac{24}{8} = 3A$$

$$4I_1 = 24$$

$$I_1 = 6A$$

KCL:

$$I_1 + I_2 = 2$$

$$I_2 = 2 - 6$$

$$I_2 = -4A$$

KCL:

$$I_1 = I_3 + I_4$$

$$I_3 = 6 - 3$$

$$I_3 = 3A$$

2.101 A single-stage transistor amplifier is modeled as shown in Fig. P2.101. Find the current in the load R_L.

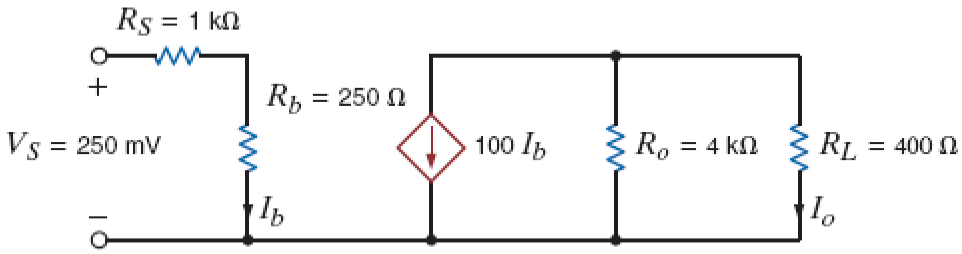
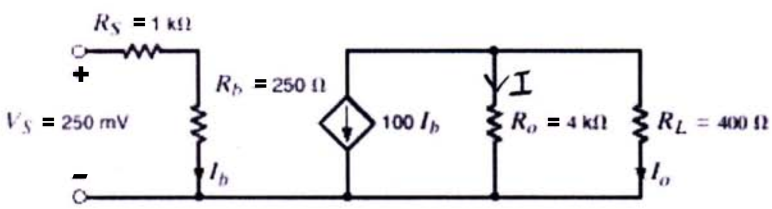


Figure P2.101

SOLUTION:



KVL:

$$V_s = I_b R_s + I_b R_b$$

$$I_b = \frac{250m}{1k + 250}$$

$$I_b = 0.2\text{ mA}$$

KCL:

$$100 I_b + I + I_o = 0$$

$$I_o = -100(0.2m) - I$$

$$I = \left(\frac{400}{400+4k}\right)(-100 I_b) = \left(\frac{400}{400+4k}\right)(-100)(0.2m)$$

$$I = -1.82\text{ mA}$$

$I_o = -0.02 - (-1.82m)$

$I_o = -18.18\ mA$

2.102 Find I_o in the network in Fig. P2.102.

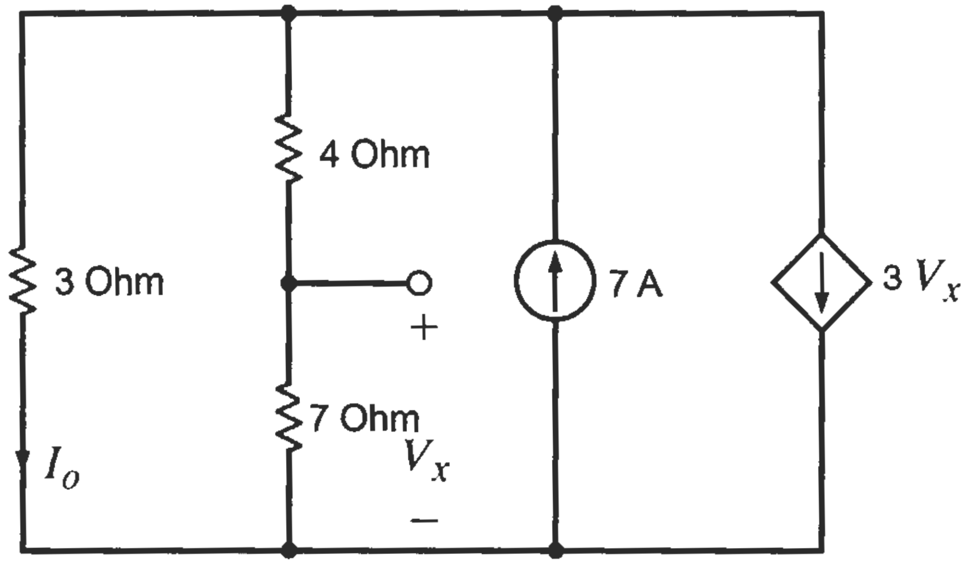
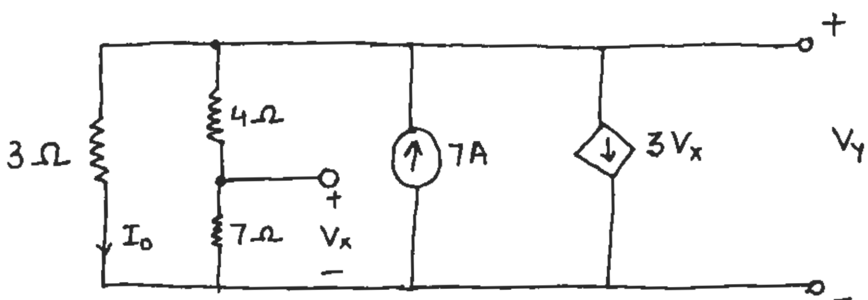


Figure P2.102

Solution: 2.102



$$7 = 3V_x + \frac{V_y}{11} + \frac{V_y}{3} \quad \ldots\ldots \quad (1)$$

$$V_x = V_y\left[\frac{7}{7+4}\right] = \frac{7}{11}V_y$$

$$V_x = \frac{7}{11}V_y \quad \ldots\ldots\ldots \quad (2)$$

Substituting (2) into (1) $\Rightarrow$ $V_y = 3\ V$

$$I_o = \frac{V_y}{3} \Rightarrow \boxed{I_o = 1\ A}$$

2.103 A typical transistor amplifier is shown in Fig. P2.103. Find the amplifier gain G (i.e., the ratio of the output voltage to the input voltage).

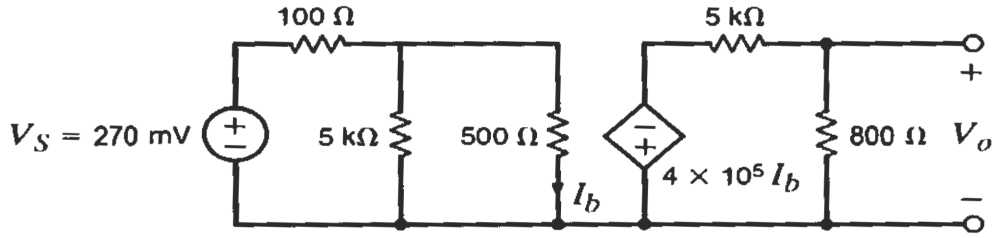
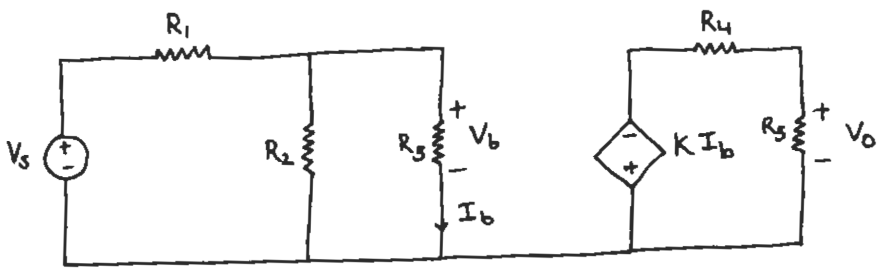


Figure P2.103

Solution: 2.103



$V_s = 0.27$ V, $R_1 = 100\,\Omega$, $R_2 = 5\,k\Omega$, $R_3 = 500\,\Omega$,

$K = 4 \times 10^5$, $R_4 = 5\,k\Omega$, $R_5 = 800\,\Omega$

$$V_b = V_s \left[\frac{R_2 \| R_3}{R_1 + (R_2 \| R_3)}\right] = 0.221 \text{ V}$$

$$I_b = \frac{V_b}{R_3} = 442\ \mu A$$

$$V_o = -K I_b \left[\frac{R_5}{R_4 + R_5}\right] \Rightarrow V_o = -24.386 \text{ V}$$

$$G = \frac{V_o}{V_s} = -90.319$$

$$\boxed{G = -90.3}$$

2.104 Find the power absorbed by the 12-kΩ resistor in the network in Fig. P2.104.

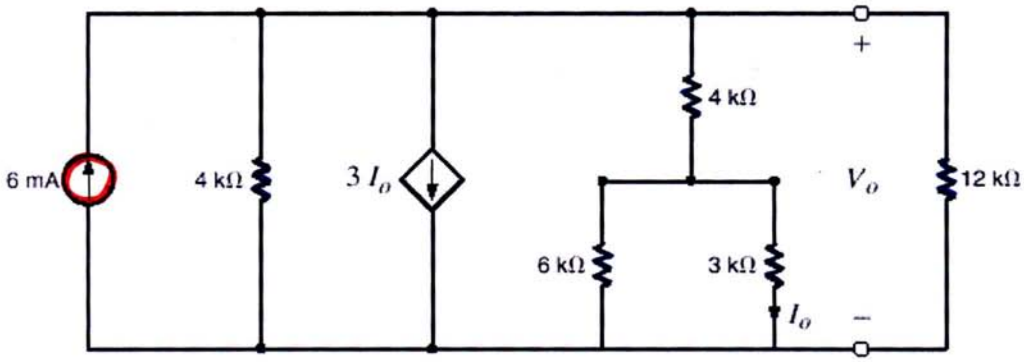
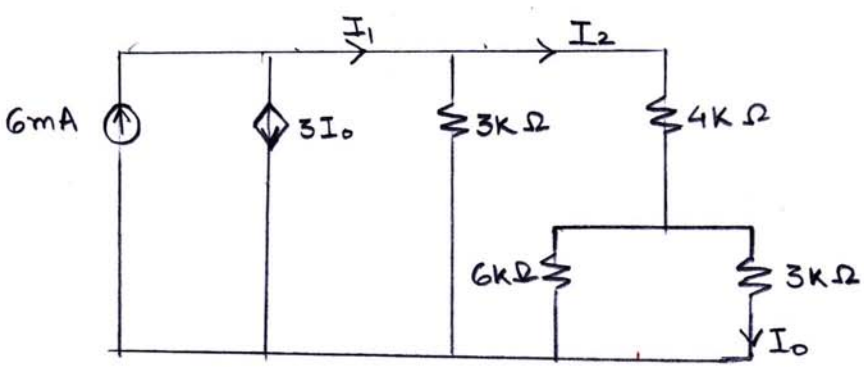


Figure P2.104

SOLUTION:

$$R = (4k \| 12k) = 3k\Omega$$



KCL:

$$3I_o + I_1 = 6m$$

$$I_1 = 6m - 3I_o$$

$$I_2 = \left(\frac{3k}{4k + (6k \| 3k) + 3k}\right)(6m - 3I_o)$$

$$I_2 = 2m - I_o$$

$$I_o = 0.8mA$$

KCL:

$$6m = \frac{V_o}{4k} + 3I_o + \frac{V_o}{6k} + \frac{V_o}{12k}$$

$$6m = \frac{V_o}{4k} + 3(0.8m) + \frac{V_o}{6k} + \frac{V_o}{12k}$$

$$V_o = 7.2V$$

$$P_{12k\Omega} = \frac{V_o^2}{12k} = \frac{(7.2)^2}{12k} = 4.32mW$$

2.105 Find the power absorbed by the 12-kΩ resistor in the network in Fig. P2.105.

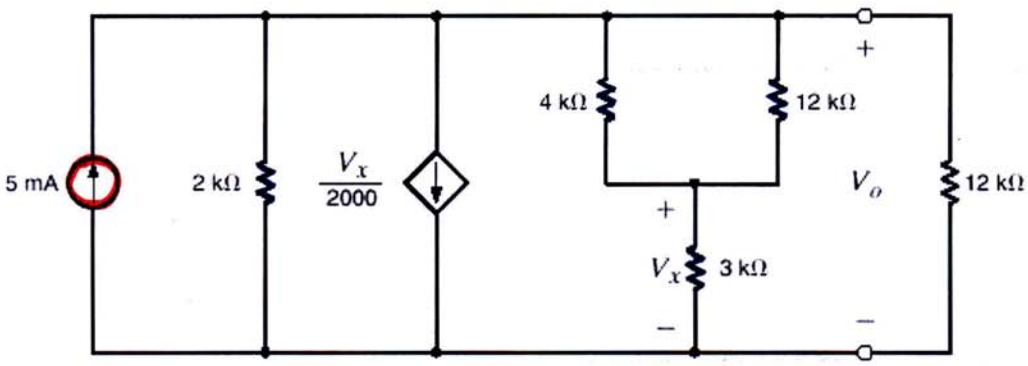
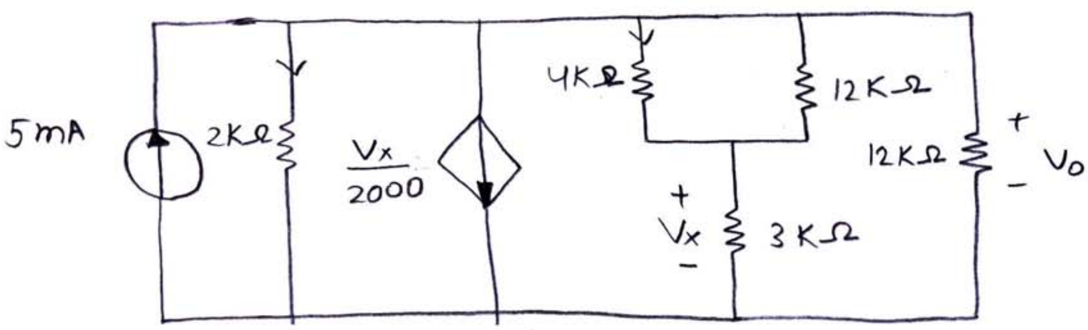


Figure P2.105

SOLUTION:



$$V_x = \left(\frac{3K}{(4K//12K)+3K}\right)V_o$$

$$V_x = \frac{V_o}{2}$$

$$\text{KCL:}\quad 5m = \frac{V_o}{2K} + \frac{V_x}{2000} + \frac{V_o}{(4K//12K)+3K} + \frac{V_o}{12K}$$

$$5m = \frac{V_o}{2K} + \frac{V_x}{2K} + \frac{V_o}{6K} + \frac{V_o}{12K}$$

$$60 = 6V_o + 6V_x + 2V_o + V_o$$

$$60 = 9V_o + 6\left(\frac{V_o}{2}\right)$$

$$V_o = 5\text{V}$$

$$P_{12k\Omega} = \frac{V_o^2}{12k} = \frac{(5)^2}{12k}$$

$$P_{12k\Omega} = 2.08\ \text{mW}$$

2.106 Find the value of k in the network in Fig. P2.106, such that the power supplied by the 6-A source is 108 W.

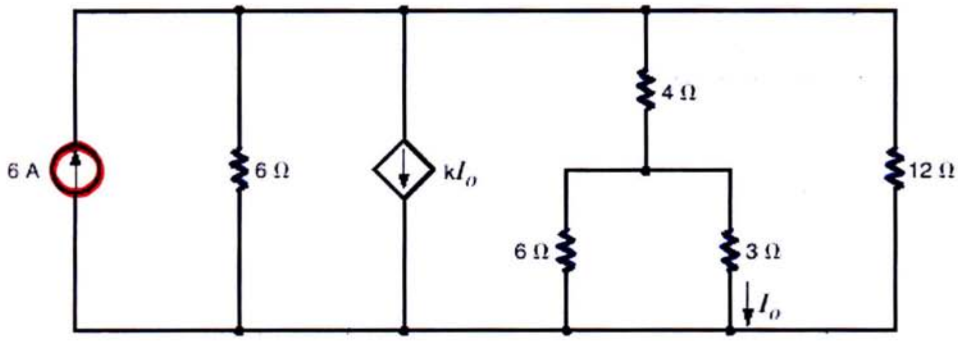
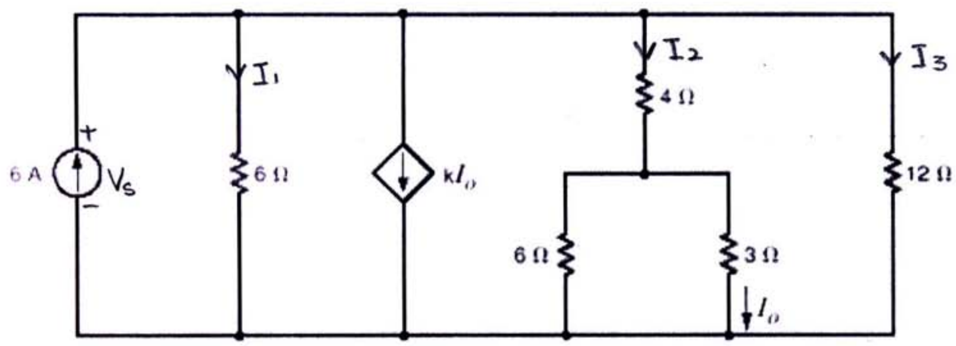


Figure P2.106

SOLUTION:



$$P_{6A} = V_s I_s$$

$$V_s = \frac{108}{6} = 18V$$

KCL:

$$6 = \frac{V_s}{6} + KI_o + \frac{V_s}{4+(6\|3)} + \frac{V_s}{12}$$

$$6 = \frac{18}{6} + KI_o + 36 + 18$$

$$12KI_o = -18$$

$$KI_o = -1.5V$$

$$I_2 = \frac{V_s}{4+(6\|3)} = \frac{18}{4+2} = 3A$$

$$I_o = \left(\frac{6}{3+6}\right) I_2 = \left(\frac{6}{3+6}\right)(3)$$

$$I_o = 2A$$

$$K = \frac{-1.5}{2}$$

$$K = -0.75$$

2FE-10 Find the current I_x in Fig. 2PFE-10.

a. 1/2 A

b. 5/3 A

c. 3/2 A

d. 8/3 A

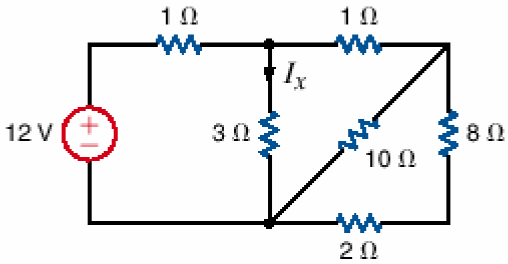
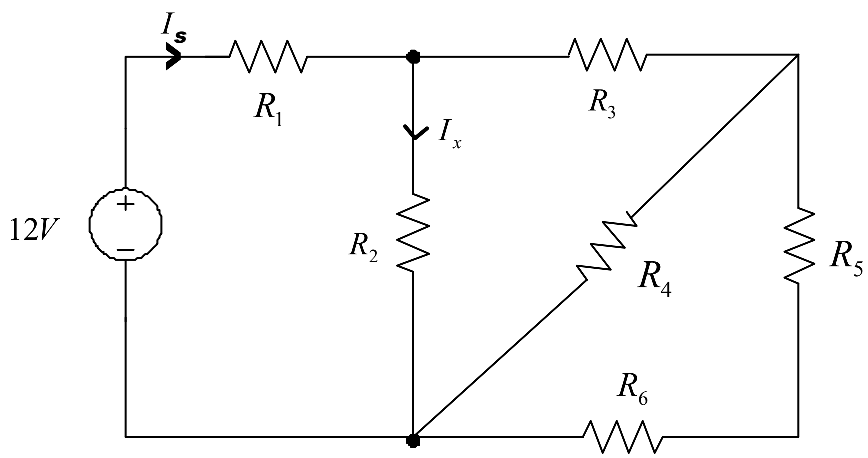


Fig. 2PFE-10

SOLUTION:



The correct answer is *d*.

$$R_{eq} = \left\{ \left[\left[(R_5 + R_6) \| R_4\right] + R_3\right] \| R_2 \right\} + R_1$$

$$R_{eq} = \left\{ \left[\left[(8+2) \| 10\right] + 1\right] \| 3 \right\} + 1$$

$$R_{eq} = (6 \| 3) + 1 = 3\Omega$$

$$I_s = \frac{12}{R_{eq}} = \frac{12}{3} = 4A$$

$$R' = \left[(R_5 + R_6) \| R_4\right] + R_3 = 6\Omega$$

$$I_x = \left(\frac{6}{3+6}\right)(4) = \frac{24}{9} = \frac{8}{3}A$$

3.1 Find both I_o and V_o in the network in Fig. P3.1 using nodal analysis.

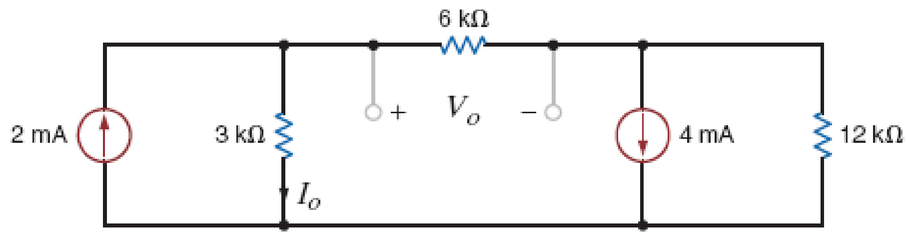
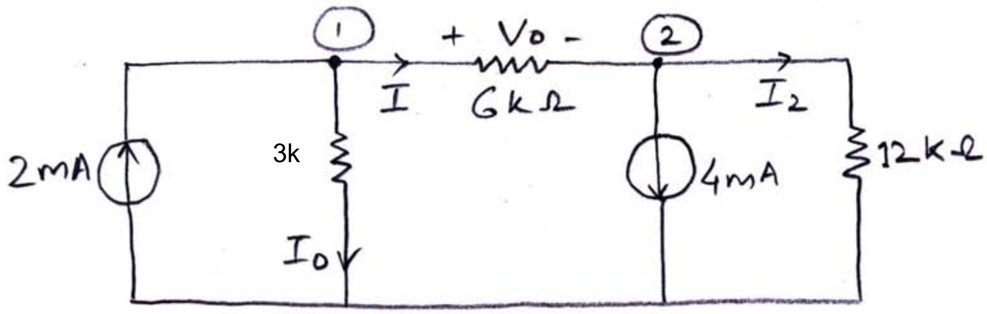


Figure P3.1

SOLUTION:



KCL at 1:

$$2m = I_o + I$$

$$\frac{V_1}{3k} + \frac{V_1 - V_2}{6k} = 2m$$

$$2V_1 + V_1 - V_2 = 12$$

$$\boxed{3V_1 - V_2 = 12}$$

KCL at 2:

$$I = 4m + I_2$$

$$\frac{V_1 - V_2}{6k} = 4m + \frac{V_2}{12k}$$

$$2V_1 - 2V_2 = 48 + V_2$$

$$\boxed{2V_1 - 3V_2 = 48}$$

$$3V_1 - V_2 = 12$$
$$2V_1 - 3V_2 = 48$$

$$V_1 = -1.71 \text{ V}$$
$$V_2 = -17.14 \text{ V}$$

$$V_o = V_1 - V_2$$

$$V_o = -1.71 - (-17.14)$$

$$V_o = 15.43\ V$$

$$I_o = \frac{V_1}{3k}$$

$$= \frac{-1.71}{3K} = -0.57$$

$$I_o = -0.57\ mA$$

3.2 Use nodal analysis to find V_1 in the circuit in Fig. P3.2.

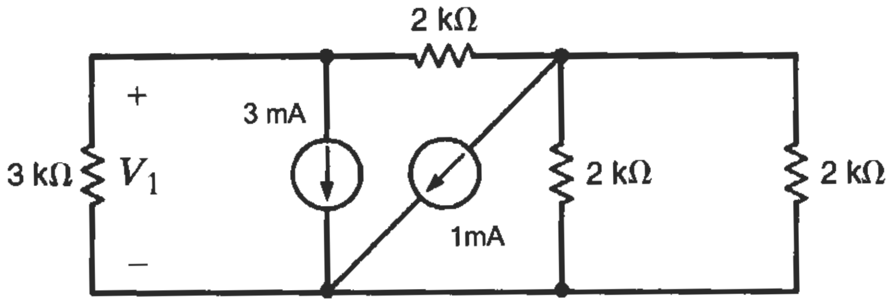
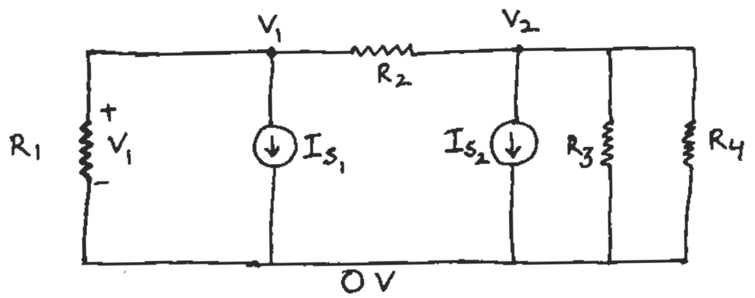


Figure P3.2

SOLUTION: 3.2



$R_1 = 3\,k\Omega,\ R_2 = R_3 = R_4 = 2\,k\Omega,\ I_{s_1} = 3\,mA,\ I_{s_2} = 1\,mA$

KCL @ V_1 : $\dfrac{V_1}{R_1} + I_{s_1} + \dfrac{V_1 - V_2}{R_2} = 0$

$$\frac{V_1}{3\times10^3} + 3\times10^{-3} + \frac{V_1 - V_2}{2\times10^3} = 0$$

$$5V_1 - 3V_2 = -18 \quad \text{———} \quad (1)$$

KCL @ V_2 : $\dfrac{V_2 - V_1}{R_2} + I_{s_2} + \dfrac{V_2}{R_3} + \dfrac{V_2}{R_4} = 0$

$$\frac{V_2 - V_1}{2\times10^3} + 1\times10^{-3} + \frac{V_2}{2\times10^3} + \frac{V_2}{2\times10^3} = 0$$

$$3V_2 - V_1 = -2 \quad \text{———} \quad (2)$$

Substituting equation (2) in (1), we get

$$V_2 = -\frac{28}{12}$$

$$V_1 = \frac{3V_2 - 18}{5} \Rightarrow \boxed{V_1 = -5V}$$

3.3 Find V_1 and V_2 in the circuit in Fig. P3.3 using nodal analysis. Then solve the problem using MATLAB and compare your answers.

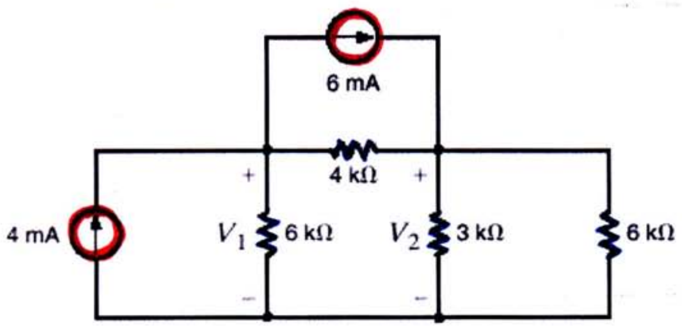
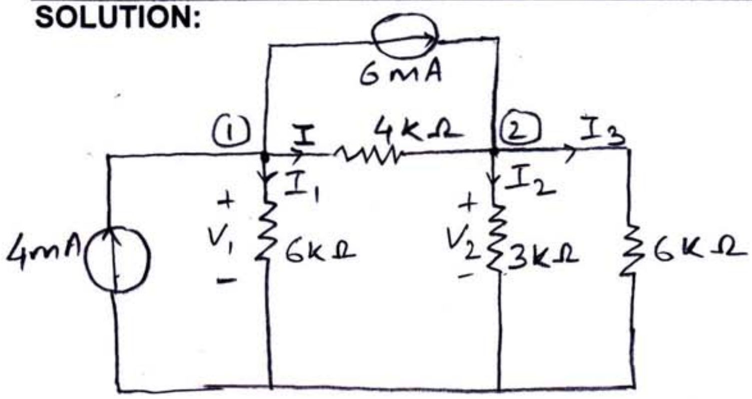


Figure P3.3

SOLUTION:



KCL at 1 : $4m = 6m + I + I_1$

$$\frac{V_1 - V_2}{4k} + \frac{V_1}{6k} = -2m$$

$$3V_1 - 3V_2 + 2V_1 = -24$$

$$\boxed{5V_1 - 3V_2 = -24}$$

KCL at 2 : $6m + I = I_2 + I_3$

$$\frac{V_2}{3k} + \frac{V_2}{6k} = 6m + \frac{V_1 - V_2}{4k}$$

$$4V_2 + 2V_2 = 72 + 3V_1 - 3V_2$$

$$\boxed{-3V_1 + 9V_2 = 72}$$

$$5V_1 - 3V_2 = -24$$
$$-3V_1 + 9V_2 = 72$$

$$V_1 = 0 \text{ V}$$
$$V_2 = 8 \text{ V}$$

```
% MATLAB Code and Solution for Problem 3.4

G = [5, -3; -3, 9];
Imatrix = [-24; 72];
V = inv(G)*Imatrix

>>
  V =
      0.00
      8.00
```

3.4 Use nodal analysis to find both V_1 and V_o in the circuit in Fig. P3.4.

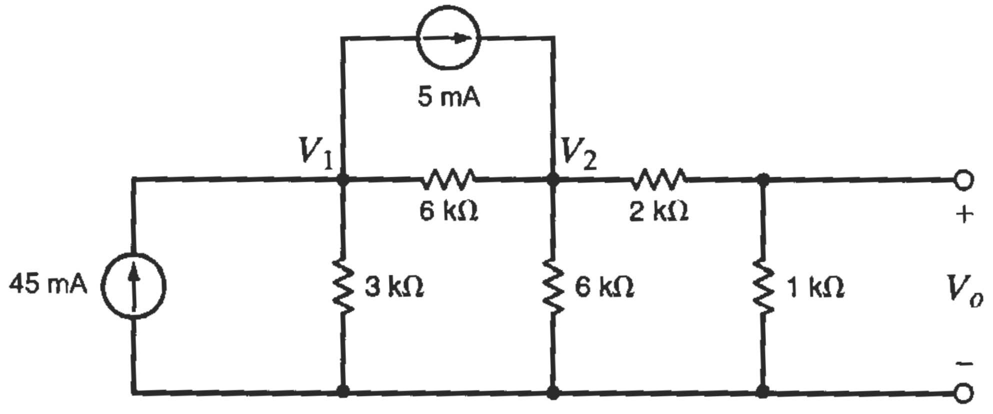
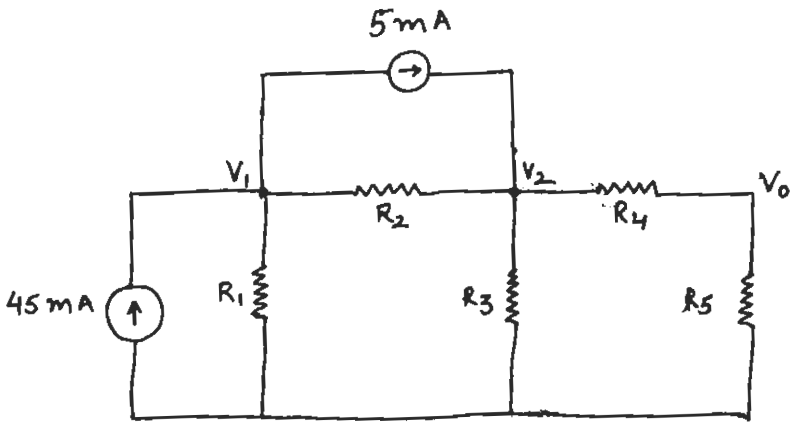


Figure P3.4

SOLUTION: 3.4



$R_1 = 3k\Omega$, $R_2 = 6k\Omega$, $R_3 = 6k\Omega$, $R_4 = 2k\Omega$, $R_5 = 1k\Omega$

KCL @ V_1 : $\dfrac{V_1 - V_2}{R_2} + \dfrac{V_1}{R_1} + I_{S_2} - I_{S_1} = 0$

$$\frac{V_1 - V_2}{6 \times 10^3} + \frac{V_1}{3 \times 10^3} + 5 \times 10^{-3} - 45 \times 10^{-3} = 0$$

$$3V_1 - V_2 = 240 \quad \text{———} \quad (1)$$

KCL @ V_2 : $\dfrac{V_2 - V_1}{R_2} + \dfrac{V_2 - V_o}{R_4} + \dfrac{V_2}{R_3} - I_{S_2} = 0$

$$\frac{V_2 - V_1}{6\times10^3} + \frac{V_2 - V_0}{2\times10^3} + \frac{V_2}{6\times10^3} - 5\times10^{-3} = 0$$

$$5V_2 - V_1 - 3V_0 = 30 \quad \text{——} \quad (2)$$

KCL at V_0 : $\dfrac{V_2 - V_0}{R_4} - \dfrac{V_0}{R_5} = 0$

$$\frac{V_2 - V_0}{2\times10^3} - \frac{V_0}{10^3} = 0$$

$$V_2 = 3V_0 \quad \text{——} \quad (3)$$

Substituting equation (3) in (2), we get

$$5(3V_0) - V_1 - 3V_0 = 30$$

$$12V_0 - 30 = V_1 \quad \text{——} \quad (4)$$

Substituting equations (3) and (4) in (1), we get

$$3(12V_0 - 30) - 3V_0 = 240$$

$$\boxed{V_0 = 10\,V}$$

Substituting the value of V_0 in equation (4), we get

$$12(10) - 30 = V_1$$

$$\Rightarrow \boxed{V_1 = 90\,V}$$

3.5 Find V_o in the network in Fig. P3.5.

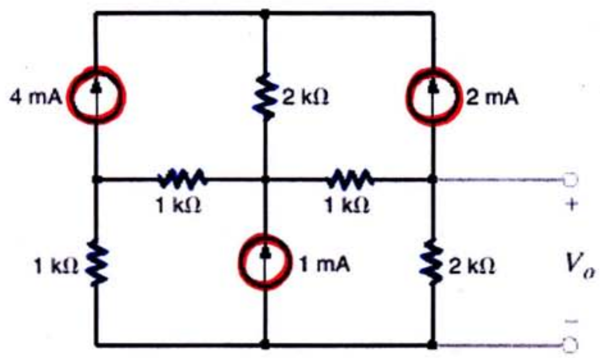
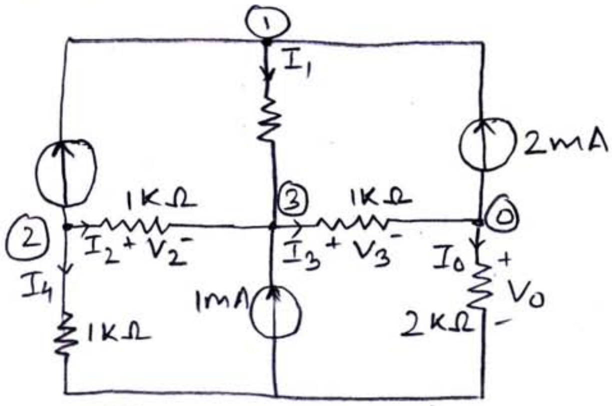


Figure P3.5

SOLUTION:



KCL at (2) : $4m + I_2 + I_4 = 0$

$$\frac{V_2 - V_3}{1K} + \frac{V_2}{1K} = -4m$$

$$V_2 - V_3 + V_2 = -4$$

$$\boxed{2V_2 - V_3 = -4}$$

KCL at (3) : $I_1 + 1m + I_2 = I_3$

$$\frac{V_1 - V_3}{2K} + 1m + \frac{V_2 - V_3}{1K} = \frac{V_3 - V_0}{1K}$$

$$V_1 - V_3 + 2 + 2V_2 - 2V_3 = 2V_3 - 2V_0$$

$$-2V_0 + 5V_3 - 2V_2 - V_1 = 2$$

$$\boxed{-2V_0 - V_1 - 2V_2 + 5V_3 = 2}$$

KCL at (0): $I_3 = 2m + I_0$

$$\frac{V_3 - V_0}{1K} = 2m + \frac{V_0}{2K}$$

$$2V_3 - 2V_0 = 4 + V_0$$

$$\boxed{-3V_0 + 2V_3 = 4}$$

KCL at (1): $4m + 2m = I_1$

$$\frac{V_1 - V_3}{2K} = 6m$$

$$\boxed{V_1 - V_3 = 12}$$

$$0V_0 + 0V_1 + 2V_2 - V_3 = -4$$
$$-2V_0 - V_1 - 2V_2 + 5V_3 = 2$$
$$-3V_0 + 0V_1 + 0V_2 + 2V_3 = 4$$
$$0V_0 + V_1 + 0V_2 - V_3 = 12$$

$V_0 = 1.6\ V$

$V_1 = 16.4\ V$

$V_2 = 0.2\ V$

$V_3 = 4.4\ V$

3.6 Use nodal analysis to find V_o in the circuit in Fig. P3.6.

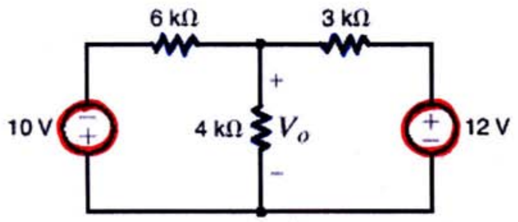
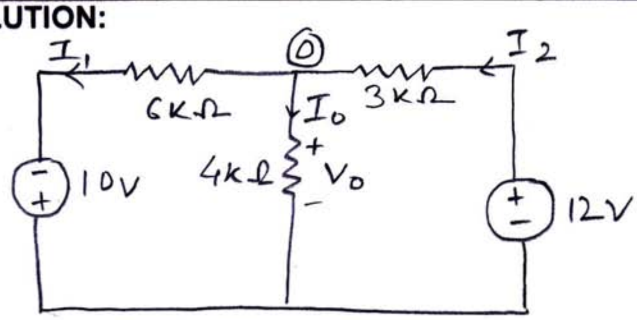


Figure P3.6

SOLUTION:



KCL at ⓪: $I_2 = I_o + I_1$

$$\frac{12 - V_o}{3K} = \frac{V_o}{4K} + \frac{V_o - (-10)}{6K}$$

$$48 - 4V_o = 3V_o + 2V_o + 20$$

$$9V_o = 28$$

$$V_o = 3.11 \text{ V}$$

3.7 Find V_o in the network in Fig. P3.7 using nodal analysis.

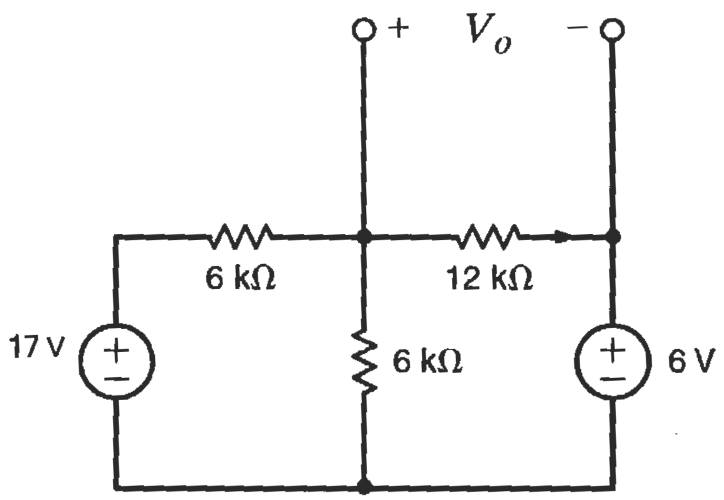
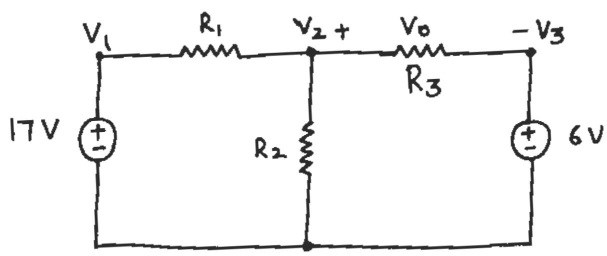


Figure P3.7

SOLUTION: 3.7



$R_1 = R_2 = 6\ k\Omega$, $R_3 = 12\ k\Omega$

@ V_1 : $V_1 = 17\ V$

KCL @ V_2 : $\dfrac{V_2 - V_1}{R_1} + \dfrac{V_2}{R_2} + \dfrac{V_2 - V_3}{R_3} = 0$ —— ①

@ V_3 : $V_3 = 6\ V$

Substituting values of V_1 and V_3 in equation ①, we get

$$\frac{V_2}{R_1} - \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_2}{R_3} - \frac{V_3}{R_3} = 0$$

$$V_2\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right] - \frac{V_1}{R_1} - \frac{V_3}{R_3} = 0$$

$$V_2\left[\frac{1}{6}+\frac{1}{6}+\frac{1}{12}\right]-\frac{17}{6}-\frac{6}{12}=0$$

$$V_2 = 8\,V$$

$$V_0 = V_2 - V_3$$

$$\boxed{V_0 = 2V}$$

3.8 Use nodal analysis to find V_o in the circuit in Fig. P3.8.

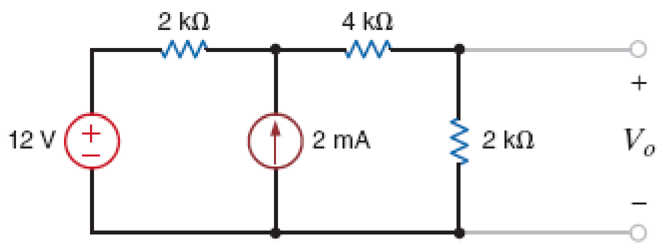
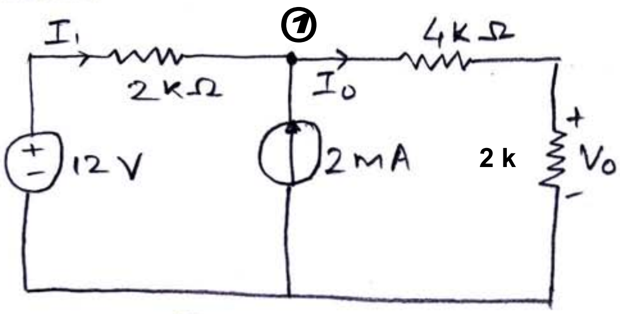


Figure P3.8

SOLUTION:



KCL at 1 : $I_1 + 2m = I_o$

$$\frac{12 - V_1}{2K} + 2m = \frac{V_1}{4K + 2K}$$

$$36 - 3V_1 + 12 = V_1$$

$$4V_1 = 48$$

$$V_1 = 12 \text{ V}$$

$$I_o = \frac{V_1}{4K + 2K}$$

$$= \frac{12}{6K}$$

$$I_o = 2 \text{ mA}$$

$$V_o = I_o (2K)$$

$$= 2m (2K)$$

$$V_o = 4 \text{ V}$$

3.9 Use nodal analysis to find V_o in the circuit in Fig. P3.9.

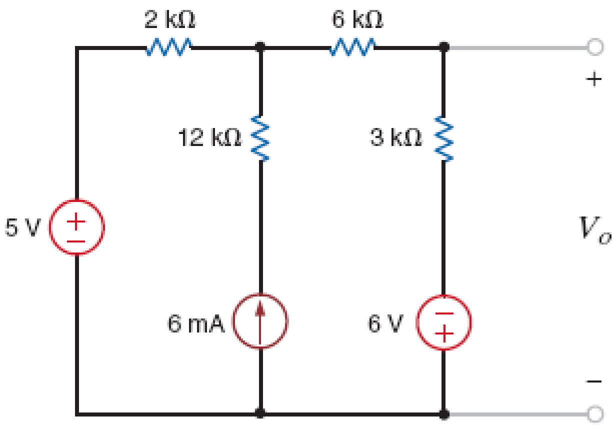
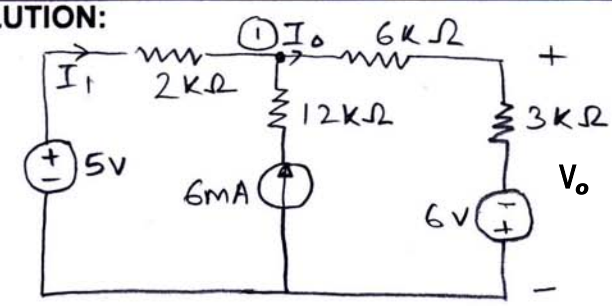


Figure P3.9

SOLUTION:



KCL at ①: $I_1 + 6m = I_o$

$$\frac{5 - V_1}{2K} + 6m = \frac{V_1 - (-6)}{6K + 3K}$$

$$45 - 9V_1 + 108 = 2V_1 + 12$$

$$11 V_1 = 141$$

$$V_1 = 12.82 \text{ V}$$

$$I_o = \frac{V_1 - (-6)}{6K + 3K}$$

$$= \frac{12.82 + 6}{9K}$$

$$I_o = 2.09 \text{ mA}$$

$$6 + V_o = 3K\, I_o$$

$$V_o = 3K(2.09m) - 6$$

$$V_o = 0.27 \text{ V}$$

3.10 Use nodal analysis to find V_o in the network in Fig. P3.10.

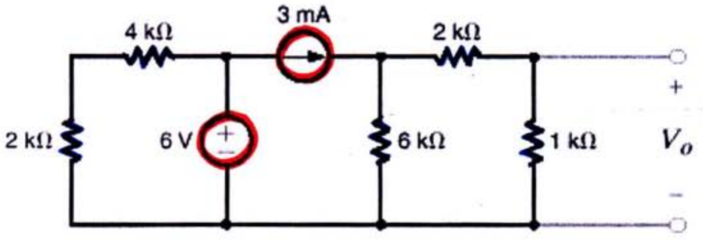
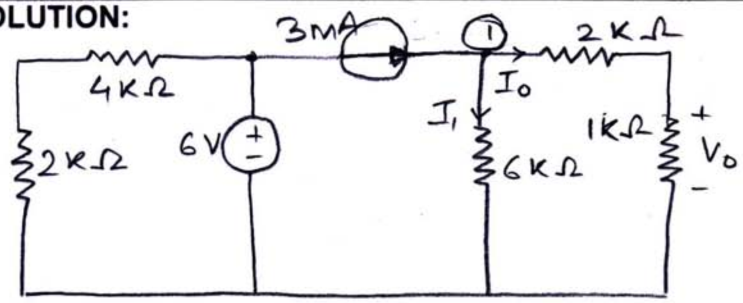


Figure P3.10

SOLUTION:



KCL at ①: $3m = I_1 + I_0$

$$\frac{V_1}{6K} + \frac{V_1}{2K+1K} = 3m$$

$$V_1 + 2V_1 = 18$$

$$3V_1 = 18$$

$$V_1 = 6 \text{ V}$$

$$I_o = \frac{V_1}{2K+1K} = \frac{6}{3K}$$

$$I_o = 2mA$$

$$V_o = I_o(1K)$$
$$= 2m(1K)$$
$$V_o = 2 \text{ V}$$

3.11 Use nodal analysis to find V_o in the circuit in Fig. P3.11.

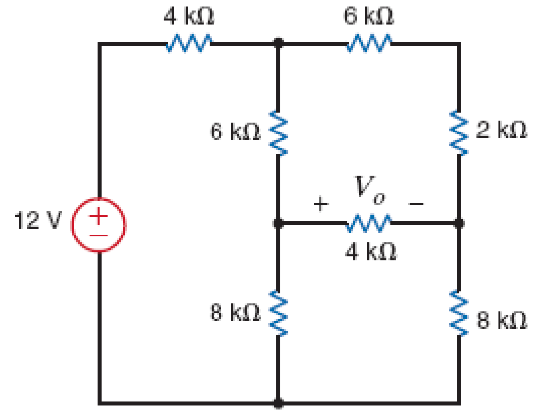
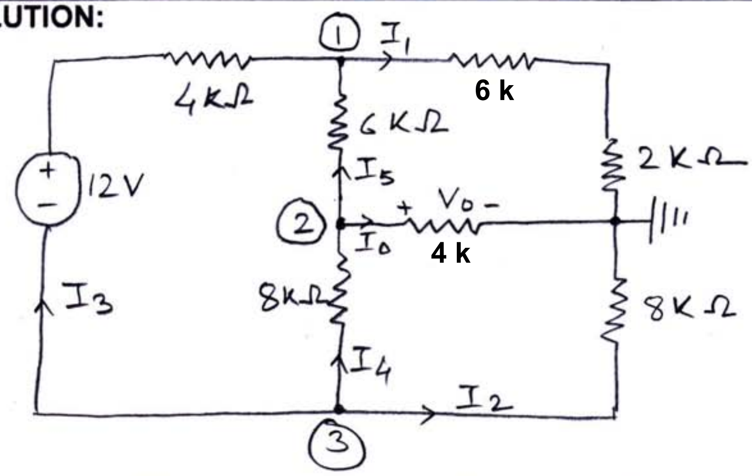


Figure P3.11

SOLUTION:



KCL at 1 :

$$I_3 + I_5 = I_1$$

$$\frac{12 - V_1}{4K} + \frac{V_2 - V_1}{6K} = \frac{V_1}{6K + 2K}$$

$$72 - 6V_1 + 4V_2 - 4V_1 = 3V_1$$

$$\boxed{13V_1 - 4V_2 = 72}$$

KCL at 2 :

$$I_4 = I_o + I_5$$

$$\frac{V_3 - V_2}{8K} = \frac{V_2}{4K} + \frac{V_2 - V_1}{6K}$$

$$3V_3 - 3V_2 = 6V_2 + 4V_2 - 4V_1$$

$$\boxed{4V_1 - 13V_2 + 3V_3 = 0}$$

KCL at 3: $I_2 + I_3 + I_4 = 0$

$$\frac{-12+V_1}{4K} + \frac{V_3}{8K} + \frac{V_3 - V_2}{8K} = 0$$

$$-24 + 2V_1 + V_3 + V_3 - V_2 = 0$$

$$\boxed{2V_1 - V_2 + 2V_3 = 24}$$

$$13V_1 - 4V_2 + 0V_3 = 72$$
$$4V_1 - 13V_2 + 3V_3 = 0$$
$$2V_1 - V_2 + 2V_3 = 24$$

$V_1 = 6.68$ V
$V_2 = 3.71$ V
$V_3 = 7.18$ V

$V_o = V_2 = 3.71$ V

3.12 Find I_o in the network in Fig. P3.12 using nodal analysis.

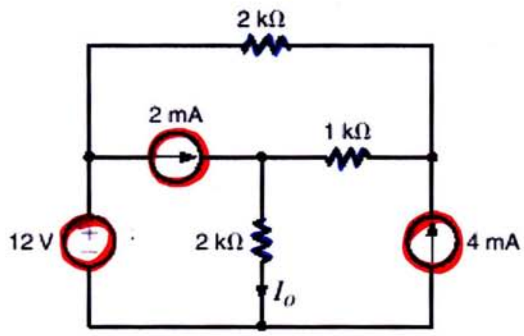
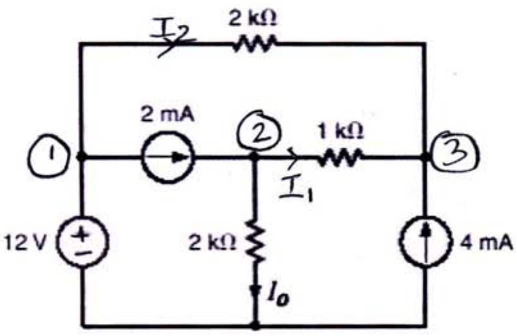


Figure P3.12

SOLUTION:



KCL at 2 :

$$2m = \frac{V_2}{2K} + \frac{V_2 - V_3}{1K}$$

$$4 = V_2 + 2V_2 - 2V_3$$

$$\boxed{3V_2 - 2V_3 = 4}$$

KCL at 3 :

$$I_1 + I_2 + 4m = 0$$

$$\frac{V_2 - V_3}{1K} + \frac{V_1 - V_3}{2K} + 4m = 0$$

$$2V_2 - 2V_3 + V_1 - V_3 + 8 = 0$$

$$V_1 = 12V$$

$$\boxed{2V_2 - 3V_3 = -20}$$

$$3V_2 - 2V_3 = 4$$

$$2V_2 - 3V_3 = -20$$

$$V_2 = 10.4 \text{ V}$$
$$V_3 = 13.6 \text{ V}$$

$$I_o = \frac{V_2}{2K}$$
$$= \frac{10.4}{2K}$$
$$I_o = 5.2 \text{ mA}$$

3.13 Use nodal analysis to solve for the node voltages in the circuit in Fig. P3.13. Also calculate the power supplied by the 1-A current source.

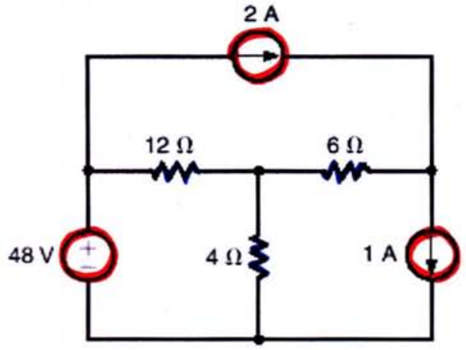
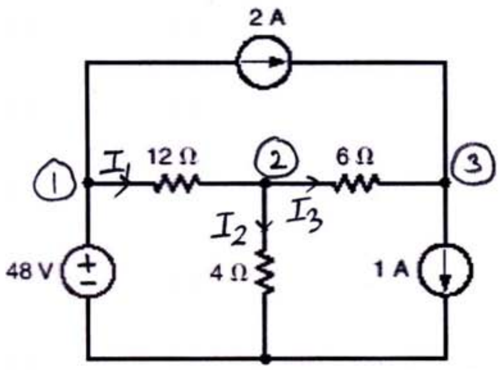


Figure P3.13

SOLUTION:



KCL at 2 : $I_1 = I_2 + I_3$

$$\frac{V_1 - V_2}{12} = \frac{V_2}{4} + \frac{V_2 - V_3}{6}$$

$$V_1 - V_2 = 3V_2 + 2V_2 - 2V_3$$

$$V_1 = 48 \text{ V}$$

$$\boxed{6V_2 - 2V_3 = 48}$$

KCL at 3 : $2 + I_3 - 1 = 0$

$$\frac{V_2 - V_3}{6} = -1$$

$$\boxed{V_2 - V_3 = -6}$$

$$6V_2 - 2V_3 = 48$$
$$V_2 - V_3 = -6$$

$$V_2 = 15\text{ V}$$
$$V_3 = 21\text{ V}$$

$$P_{1A} = V_3(1)$$
$$= 21\,(1)$$

$$P_{1A} = 21\text{ W}$$

3.14 Find V_o in the network in Fig. P3.14 using nodal equations.

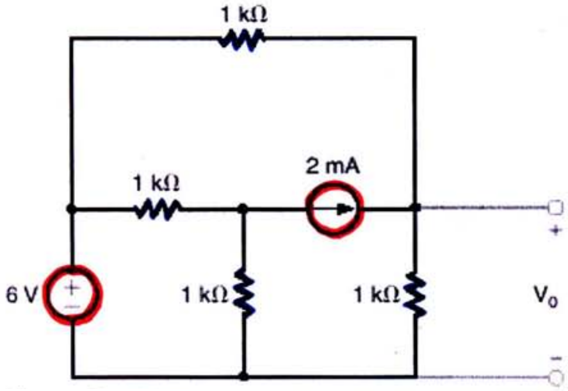
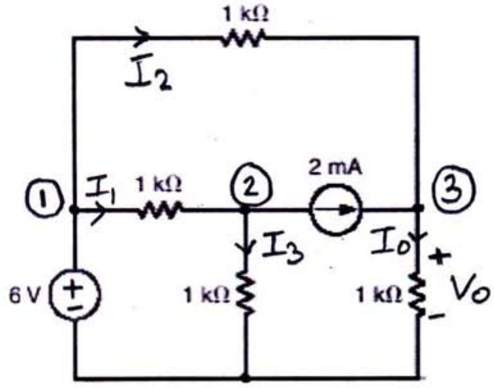


Figure P3.14

SOLUTION:



KCL at 2 : $I_1 = I_3 + 2m$

$$\frac{V_1 - V_2}{1K} = \frac{V_2}{1K} + 2m$$

$$V_1 - V_2 = V_2 + 2$$

$$\boxed{V_1 - 2V_2 = 2}$$

$$V_1 = 6\text{ V}$$

$$-2V_2 = -4$$

$$V_2 = 2\text{ V}$$

KCL at 3 : $I_2 + 2m = I_o$

$$\frac{V_1 - V_3}{1K} + 2m = \frac{V_3}{1K}$$

$$V_1 - V_3 + 2 = V_3$$

$$2V_3 = 8$$

$$V_3 = 4 \text{ V}$$

$$V_o = V_3$$

$$V_o = 4 \text{ V}$$

3.15 Find I_o in the network in Fig. P3.15 using nodal analysis.

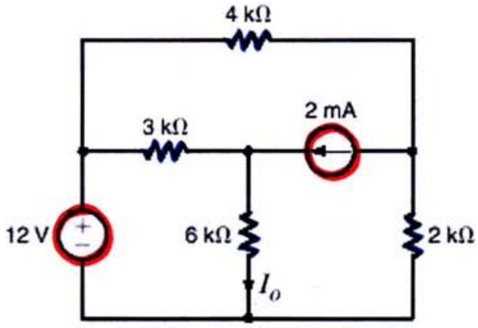
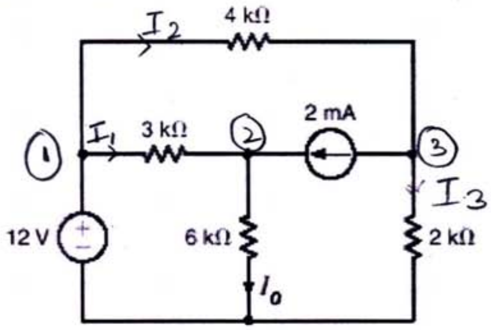


Figure P3.15

SOLUTION:



KCL at 2 : $I_1 + 2m = I_0$

$$\frac{V_1 - V_2}{3K} + 2m = \frac{V_2}{6K}$$

$$2V_1 - 2V_2 + 12 = V_2$$

$$\boxed{2V_1 - 3V_2 = -12}$$

KCL at 3 : $I_2 = 2m + I_3$

$$\frac{V_1 - V_3}{4K} = 2m + \frac{V_3}{2K}$$

$$V_1 - V_3 = 8 + 2V_3$$

$$\boxed{V_1 - 3V_3 = 8}$$

$$V_1 = 12\ V$$

$$2(12) - 3V_2 = -12$$

$$-3V_2 = -36$$

$$V_2 = 12\ V$$

$$I_o = \frac{V_2}{6K}$$

$$= \frac{12}{6K}$$

$$I_o = 2mA$$

3.16 Use nodal analysis to find I_o in the circuit in Fig. P3.16.

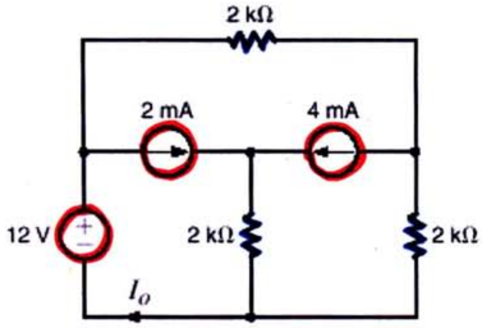
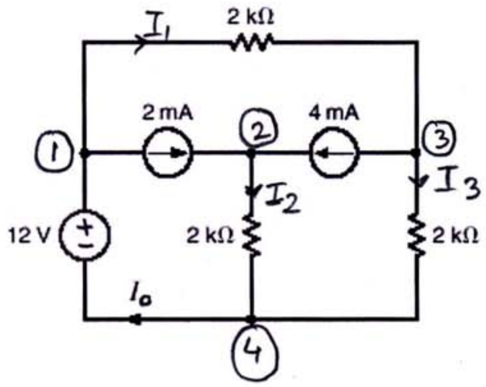


Figure P3.16

SOLUTION:



KCL at 2 : $2m + 4m = I_2$

$$\frac{V_2}{2K} = 6m$$

$$V_2 = 12V$$

KCL at 3 : $I_1 = 4m + I_3$

$$\frac{V_1 - V_3}{2K} = 4m + \frac{V_3}{2K}$$

$$V_1 - V_3 = 8 + V_3$$

$$2V_3 = V_1 - 8$$

$$V_1 = 12 \ V$$

$$2V_3 = 12 - 8$$

$$V_3 = 2 \ V$$

$$I_2 = \frac{V_2}{2K}$$

$$I_2 = \frac{12}{2K} = 6mA$$

$$I_3 = \frac{V_3}{2K} = \frac{2}{2K} = 1mA$$

KCL at 4:

$$I_2 + I_3 = I_0$$

$$I_0 = 6m + 1m$$

$$I_0 = 7mA$$

3.17 Find V_o in the circuit in Fig. P3.17 using nodal analysis.

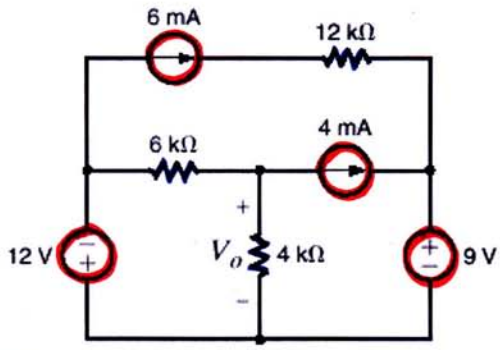
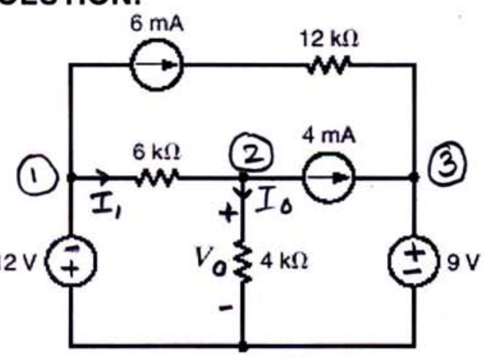


Figure P3.17

SOLUTION:



KCL at 2 : $I_1 = I_o + 4m$

$$\frac{V_1 - V_2}{6K} = \frac{V_2}{4K} + 4m$$

$$2V_1 - 2V_2 = 3V_2 + 48$$

$$\boxed{2V_1 - 5V_2 = 48}$$

$$V_1 = -12\text{ V}$$

$$2(-12) - 5V_2 = 48$$

$$V_2 = -14.4\text{ V}$$

$$V_o = V_2 = -14.4\text{ V}$$

$$V_o = -14.4\text{ V}$$

3.18 Use nodal analysis to find V_o in the network in Fig. P3.18.

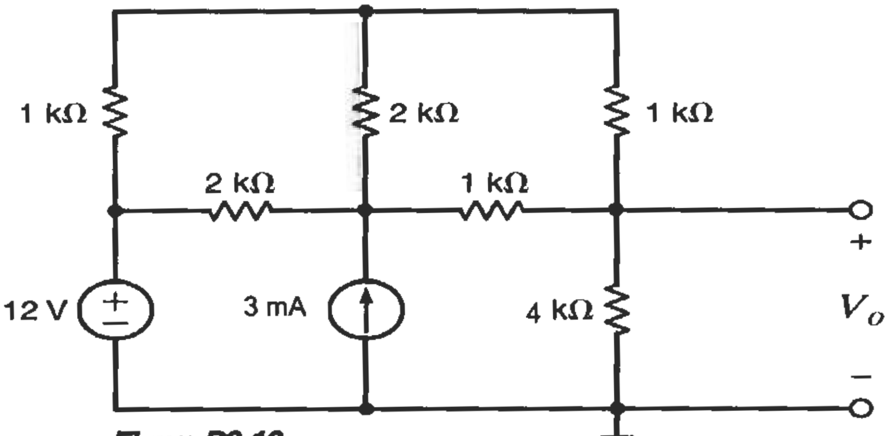
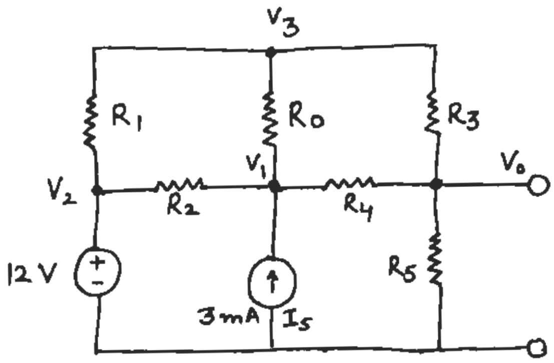


Figure P3.18

SOLUTION: 3.18



$V_2 = 12\text{ V}$

$R_5 = 4k\Omega$, $R_1 = 1k\Omega$, $R_2 = 2k\Omega$, $R_3 = 1k\Omega$, $R_4 = 1k\Omega$, $R_0 = 2k\Omega$

KCL @ V_1 : $\dfrac{V_1 - V_0}{R_4} + \dfrac{V_1 - V_3}{R_0} + \dfrac{V_1 - V_2}{R_2} = I_s$

$$\frac{V_1 - V_0}{1\times10^3} + \frac{V_1 - V_3}{2\times10^3} + \frac{V_1 - 12}{2\times10^3} = 3\times10^{-3}$$

$$2V_1 - 2V_0 + V_1 - V_3 + V_1 - 12 = 6$$

$$4V_1 - V_3 - 2V_0 = 18 \qquad \text{—— } (1)$$

KCL @ V_3: $\dfrac{V_3 - V_2}{R_1} + \dfrac{V_3 - V_1}{R_0} + \dfrac{V_3 - V_0}{R_3} = 0$

$$\frac{V_3 - 12}{1\times10^3} + \frac{V_3 - V_1}{2\times10^3} + \frac{V_3 - V_0}{1\times10^3} = 0$$

$$-V_1 + 5V_3 - 2V_0 = 24 \quad \text{—— } (2)$$

KCL @ V_0: $\dfrac{V_0 - V_3}{R_3} + \dfrac{V_0 - V_1}{R_4} + \dfrac{V_0}{R_5} = 0$

$$\frac{V_0 - V_3}{1\times10^3} + \frac{V_0 - V_1}{1\times10^3} + \frac{V_0}{4\times10^3} = 0$$

$$-4V_1 - 4V_3 + 9V_0 = 0 \quad \text{—— } (3)$$

From equation (1)

$$V_1 = \frac{18 + V_3 + 2V_0}{4} \quad \text{—— } (4)$$

Substituting equation (4) in (2), we get

$$19V_3 - 10V_0 = 114 \quad \text{—— } (5)$$

Substituting equation (4) in (3), we get

$$-4V_1 - 4V_3 + 9V_0 = 0$$

$$-\cancel{4}\left[\frac{18 + V_3 + 2V_0}{\cancel{4}}\right] - 4V_3 + 9V_0 = 0$$

$$-5V_3 + 7V_0 = 18 \quad \text{—— } (6)$$

From equations (5) and (6), we get

$$83V_0 = 912$$

$$V_0 = \frac{912}{83} = 10.99$$

$$\boxed{V_0 = 11.0V}$$

3.19 Find I_o in the circuit in Fig. P3.19 using nodal analysis.

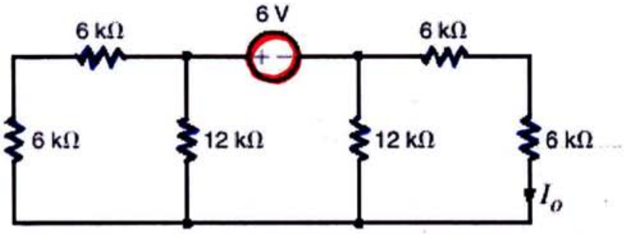
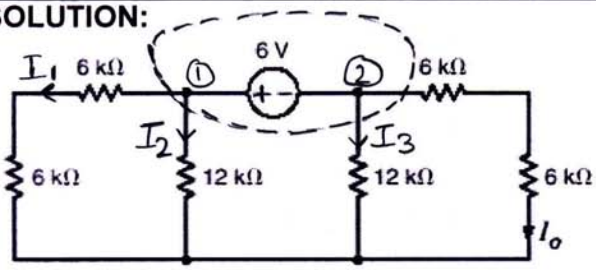


Figure P3.19

SOLUTION:



KCL at supernode : $I_1 + I_2 + I_3 + I_o = 0$

$$\frac{V_1}{6K+6K} + \frac{V_1}{12K} + \frac{V_2}{12K} + \frac{V_2}{6K+6K} = 0$$

$$V_1 + V_1 + V_2 + V_2 = 0$$

$$\boxed{2V_1 + 2V_2 = 0}$$

$$\boxed{V_1 - V_2 = 6}$$

$$2V_1 + 2V_2 = 0$$
$$V_1 - V_2 = 6$$

$$V_1 = 3 \text{ V}$$
$$V_2 = -3 \text{ V}$$

$$I_o = \frac{V_2}{12k}$$
$$= \frac{-3}{12k}$$

$$I_o = -0.25 \text{ mA}$$

3.20 Use nodal analysis to find I_o in the circuit in Fig. P3.20.

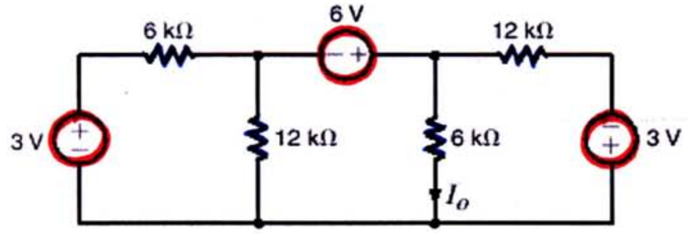
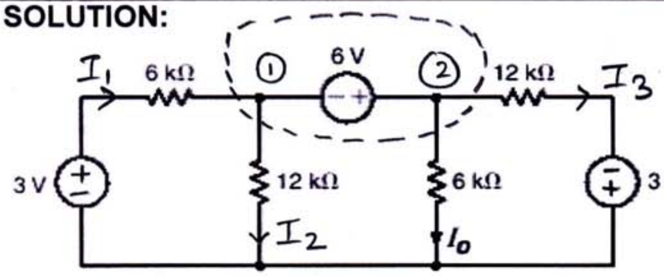


Figure P3.20

SOLUTION:



KCL at supernode : $I = I_2 + I_o + I_3$

$$\frac{3-V_1}{6K} = \frac{V_1}{12K} + \frac{V_2}{6K} + \frac{V_2-(-3)}{12K}$$

$$6 - 2V_1 = V_1 + 2V_2 + V_2 + 3$$

$$\boxed{3V_1 + 3V_2 = 3}$$

$$V_2 - V_1 = 6$$

$$\boxed{-V_1 + V_2 = 6}$$

$$3V_1 + 3V_2 = 3$$
$$-V_1 + V_2 = 6$$

$$V_1 = -2.5 \text{ V}$$
$$V_2 = 3.5 \text{ V}$$

$$I_o = \frac{V_2}{6K}$$
$$= \frac{3.5}{6K}$$
$$I_o = 0.583 \text{ mA}$$

3.21 Using nodal analysis, find V_o in the network in Fig. P3.21.

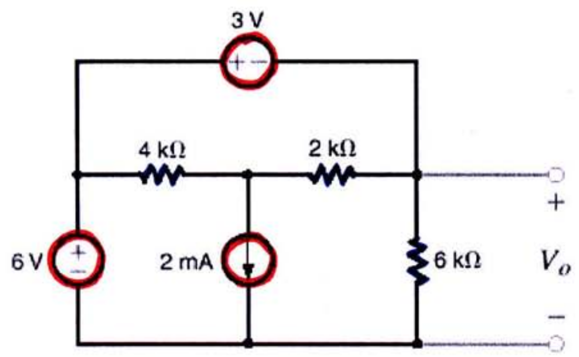
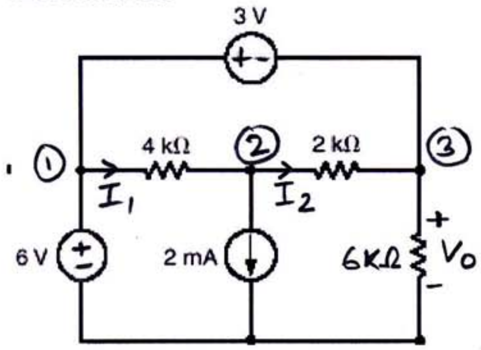


Figure P3.21

SOLUTION:



KCL at ② : $I_1 = 2m + I_2$

$$\frac{V_1 - V_2}{4K} = 2m + \frac{V_2 - V_3}{2K}$$

$$V_1 - V_2 = 8 + 2V_2 - 2V_3$$

$$\boxed{3V_2 - 2V_3 = -2}$$

$$V_1 - V_3 = 3$$

$$-V_3 = 3 - 6$$

$$V_3 = 3V$$

$$V_o = V_3 = 3\ V$$

$$V_o = 3\ V$$

3.22 Find V_o in the network in Fig. P3.22 using nodal analysis.

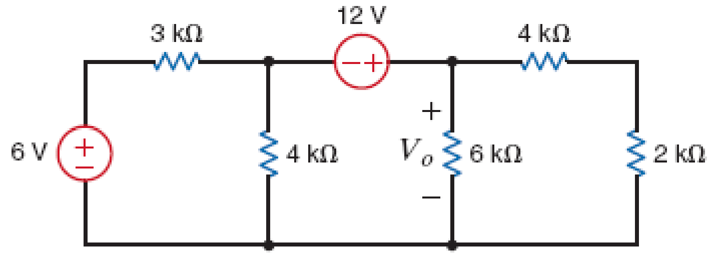
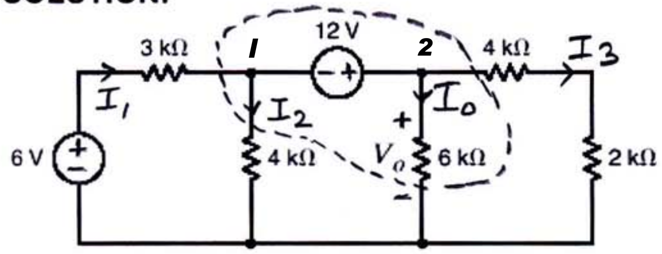


Figure P3.22

SOLUTION:



KCL at supernode : $I_1 = I_2 + I_o + I_3$

$$\frac{6 - V_1}{3K} = \frac{V_1}{4K} + \frac{V_2}{6K} + \frac{V_2}{4K + 2K}$$

$$24 - 4V_1 = 3V_1 + 2V_2 + 2V_2$$

$$\boxed{7V_1 + 4V_2 = 24}$$

$$V_2 - V_1 = 12$$

$$\boxed{-V_1 + V_2 = 12}$$

$$7V_1 + 4V_2 = 24$$
$$-V_1 + V_2 = 12$$

$$V_1 = -2.18 \text{ V}$$
$$V_2 = 9.82 \text{ V}$$
$$V_o = V_2 = 9.82 \text{ V}$$

$$V_o = 9.82 \text{ V}$$

3.23 Find V_o in the circuit in Fig. P3.23 using nodal analysis.

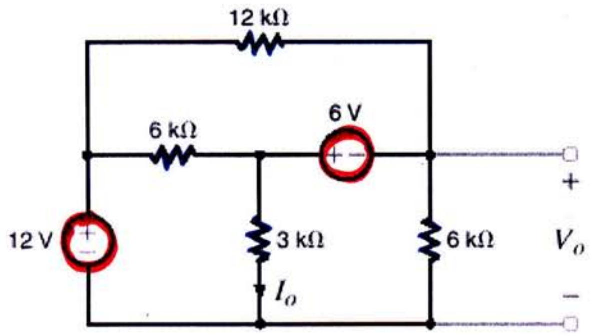
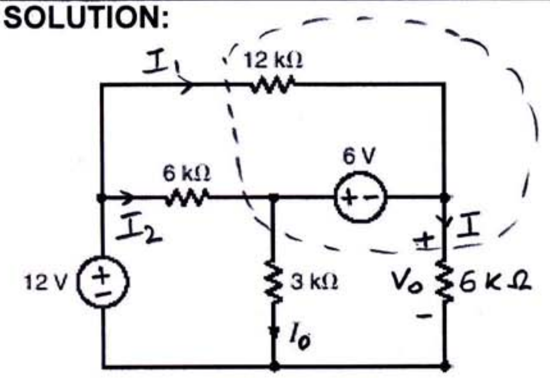


Figure P3.23

SOLUTION:



KCL at supernode : $I_1 + I_2 = I_o + I$

$$\frac{V_1 - V_3}{12K} + \frac{V_1 - V_2}{6K} = \frac{V_2}{3K} + \frac{V_3}{6K}$$

$$V_1 - V_3 + 2V_1 - 2V_2 = 4V_2 + 2V_3$$

$$V_1 = 12V$$

$$\boxed{6V_2 + 3V_3 = 36}$$

$$\boxed{V_2 - V_3 = 6}$$

$$6V_2 + 3V_3 = 36$$
$$V_2 - V_3 = 6$$

$$V_2 = 6V$$
$$V_3 = 0V$$
$$V_o = V_3 = 0\ V$$
$$V_o = 0V$$

3.24 Use nodal analysis to find V_o in the circuit in Fig. P3.24.

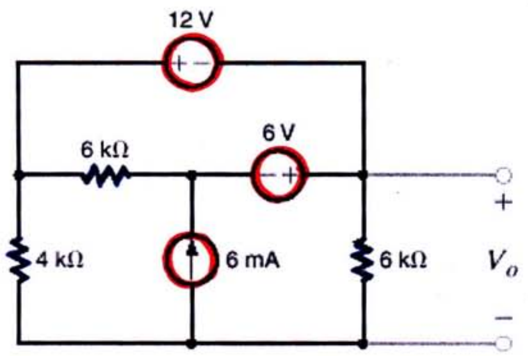
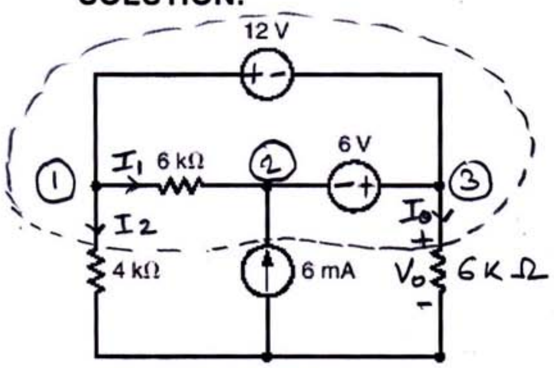


Figure P3.24

SOLUTION:



KCL at supernode: $6m = I_2 + I_o$

$$\frac{V_1}{4K} + \frac{V_3}{6K} = 6m$$

$$\boxed{3V_1 + 2V_3 = 72}$$

$$\boxed{V_1 - V_3 = 12}$$

$$3V_1 + 2V_3 = 72$$
$$V_1 - V_3 = 12$$

$$V_1 = 19.2 \text{ V}$$
$$V_3 = 7.2 \text{ V}$$

$$V_o = V_3 = 7.2 \text{ V}$$

$$V_o = 7.2 \text{ V}$$

3.25 Find V_o in the circuit in Fig. P3.25.

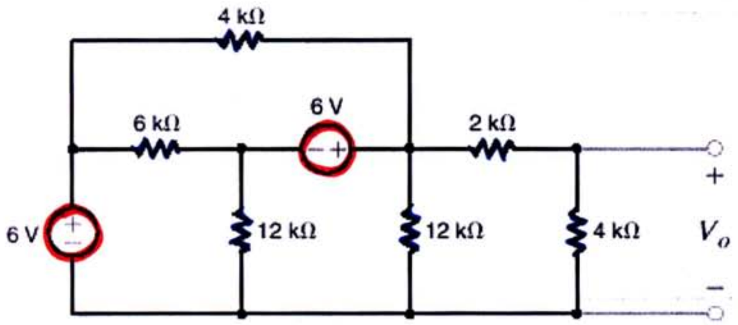
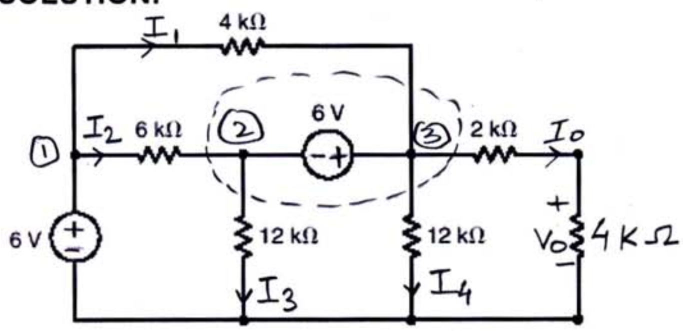


Figure P3.25

SOLUTION:



KCL at supernode : $I_1 + I_2 = I_3 + I_4 + I_o$

$$\frac{V_1 - V_3}{4K} + \frac{V_1 - V_2}{6K} = \frac{V_2}{12K} + \frac{V_3}{12K} + \frac{V_3}{2K + 4K}$$

$$3V_1 - 3V_3 + 2V_1 - 2V_2 = V_2 + V_3 + 2V_3$$

$V_1 = 6V$

$$\boxed{3V_2 + 6V_3 = 30}$$

$V_3 - V_2 = 6$

$$\boxed{-V_2 + V_3 = 6}$$

$3V_2 + 6V_3 = 30$

$-V_2 + V_3 = 6$

$V_2 = -0.667\ V$

$V_3 = 5.33\ V$

$$I_o = \frac{V_3}{2K + 4K} = \frac{5.33}{6K} = 0.888\ mA$$

$$V_o = I_o(4K) = 0.888(4) = 3.55\ V$$

3.26 Find V_o in the circuit in Fig. P3.26 using nodal analysis.

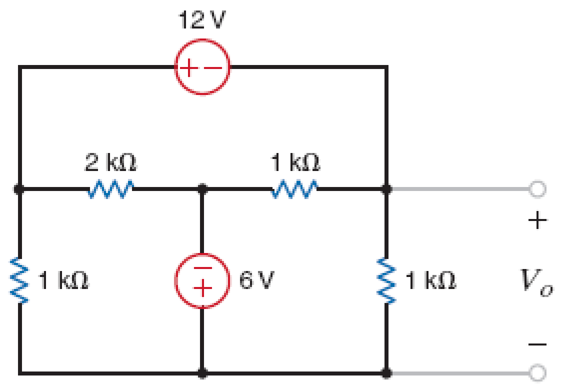
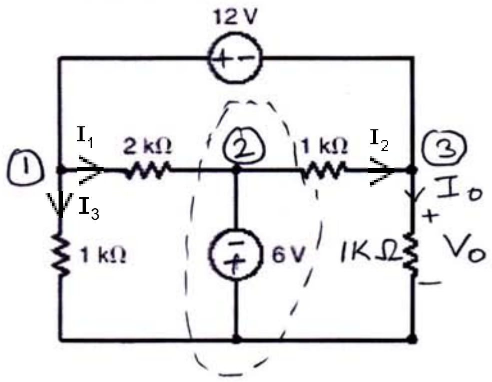


Figure P3.26

SOLUTION:



KCL at supernode : $I_1 + I_3 + I_o = I_2$

$$\frac{V_1 - V_2}{2K} + \frac{V_1}{1K} + \frac{V_3}{1K} = \frac{V_2 - V_3}{1K}$$

$$V_1 - V_2 + 2V_1 + 2V_3 = 2V_2 - 2V_3$$

$$V_2 = -6V$$

$$\boxed{3V_1 + 4V_3 = -18}$$

$$\boxed{V_1 - V_3 = 12}$$

$$V_1 = 4.29 \ V$$

$$V_3 = -7.71 \ V$$

$$V_o = V_3 = -7.71 \ V$$

$$V_o = -7.71 \ V$$

3.27 Use nodal analysis to find V_o in the circuit in Fig. P3.27.

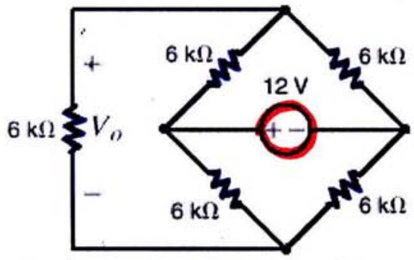
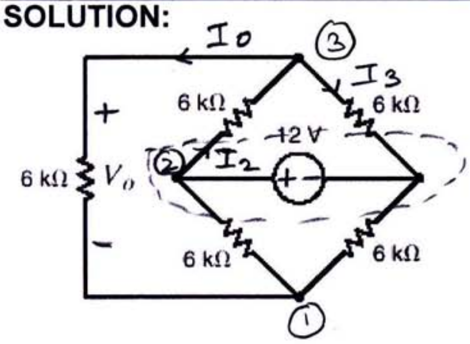


Figure P3.27

SOLUTION:



KCL at supernode: $I_1 + I_4 + I_3 = I_2$

$$\frac{V_1}{6K} + \frac{V_1 - V_2}{6K} + \frac{V_3}{6K} = \frac{V_2 - V_3}{6K}$$

$$V_1 + V_1 - V_2 + V_3 = V_2 - V_3$$

$$\boxed{2V_1 - 2V_2 + 2V_3 = 0}$$

KCL at 1 : $I_o = I_1 + I_4$

$$\frac{V_3 - V_1}{6K} = \frac{V_1}{6K} + \frac{V_1 - V_2}{6K}$$

$$V_3 - V_1 = V_1 + V_1 - V_2$$

$$\boxed{3V_1 - V_2 - V_3 = 0} \qquad \boxed{V_2 = 12V}$$

$$\boxed{2V_1 + 2V_3 = 24} \qquad \boxed{3V_1 - V_3 = 12}$$

$$2V_1 + 2V_3 = 24$$
$$3V_1 - V_3 = 12$$

$$2V_1 + 2V_3 = 24$$
$$3V_1 - V_3 = 12$$

$$V_1 = 6\text{ V}$$
$$V_3 = 6\text{ V}$$

$$V_o = V_3 - V_1 = 6 - 6$$
$$V_o = 0\text{ V}$$

It should be noted that this circuit is a balanced Wheatstone bridge. Therefore, the output voltage is zero.

3.28 Use nodal analysis to find V_o in the circuit in Fig. P3.28.

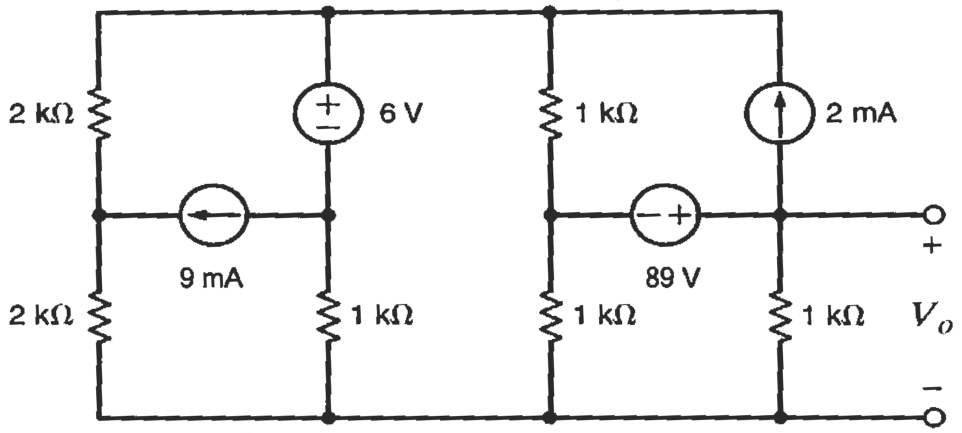
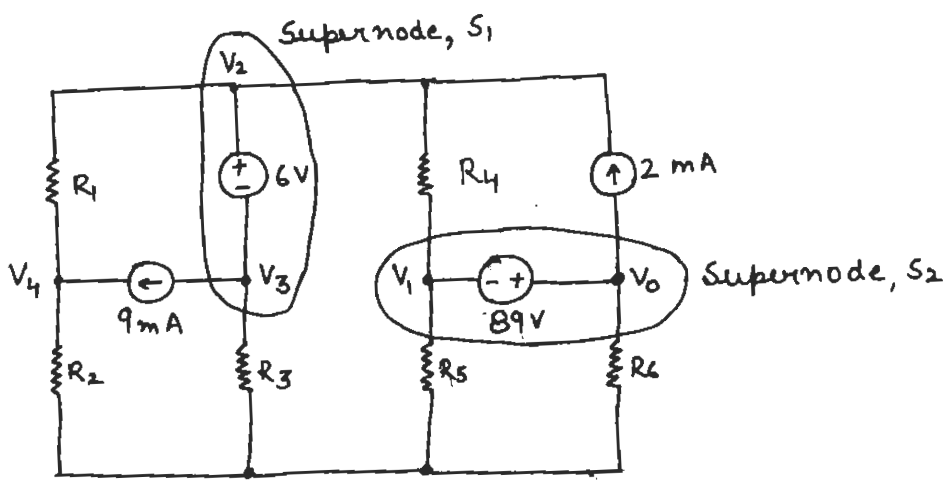


Figure P3.28

SOLUTION: 3.28



$R_1 = R_2 = 2\ k\Omega$, $R_3 = R_4 = R_5 = R_6 = 1\ k\Omega$

$$V_2 - V_3 = 6\ V \qquad \text{— ①}$$

$$V_o - V_1 = 89\ V \qquad \text{— ②}$$

KCL @ S_1: $\dfrac{V_2 - V_4}{R_1} + \dfrac{V_2 - V_1}{R_4} - 2\times10^{-3} + 9\times10^{-3} + \dfrac{V_3}{R_3} = 0$

$$-2V_1 + 3V_2 + 2V_3 - V_4 = -14 \qquad \text{— ③}$$

KCL @ S_2: $2\times10^{-3} + \dfrac{V_o}{R_6} + \dfrac{V_1 - V_2}{R_4} + \dfrac{V_1}{R_5} = 0$

$$V_o + 2V_1 - V_2 = -2 \qquad \text{— ④}$$

KCL at V_4: $\dfrac{V_4 - V_2}{R_1} - 9\times 10^{-3} + \dfrac{V_4}{R_2} = 0$

$$V_4 = 9 + \frac{V_2}{2} \qquad \text{---} \qquad (5)$$

Substituting equations (1), (2) and (5) in (3), we get

$$-2(V_0 - 89) + 3V_2 + 2(V_2 - 6) - \left(9 + \frac{V_2}{2}\right) = -14$$

$$-4V_0 + 9V_2 = -342 \qquad \text{---} \qquad (6)$$

Substituting equation (1) in (4), we get

$$V_2 = 3V_0 - 176$$

Substituting the value of V_2 in equation (6), we get

$$-4V_0 + 9(3V_0 - 176) = -342$$

$$V_0 = 53.7 \text{ V}$$

$$\boxed{V_0 = 54.0 \text{ V}}$$

3.29 Find V_o in the network in Fig. P3.29.

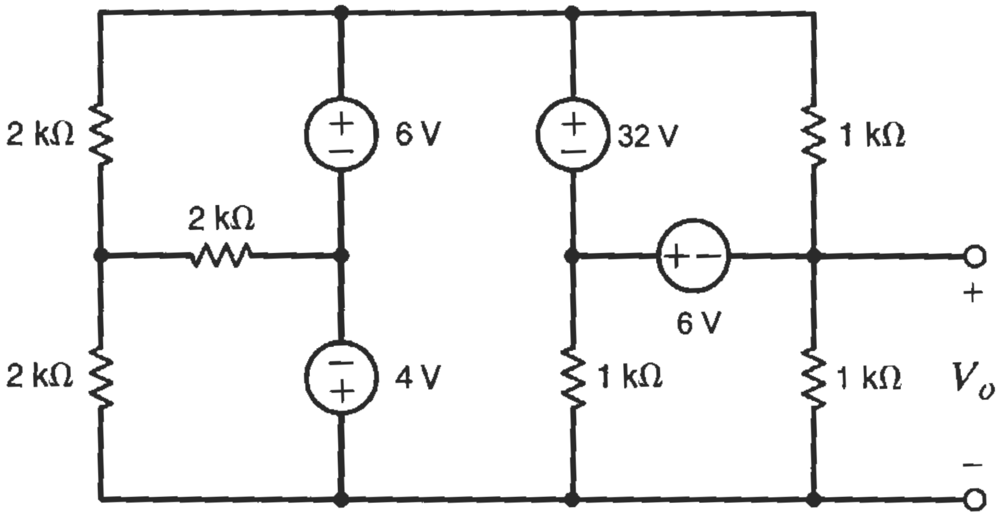
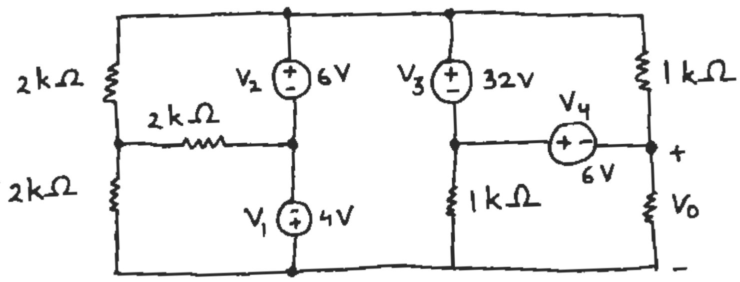


Figure P3.29

SOLUTION: 3.29



KVL : $V_1 - V_2 + V_3 + V_4 + V_o = 0$

$4 - 6 + 32 + 6 + V_o = 0$

$36 + V_o = 0$

$\boxed{V_o = -36.0 \text{ V}}$

3.30 Find I_o in the circuit in Fig. P3.30 using nodal analysis.

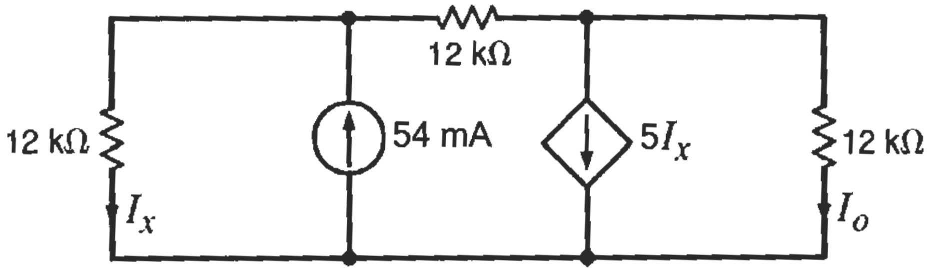
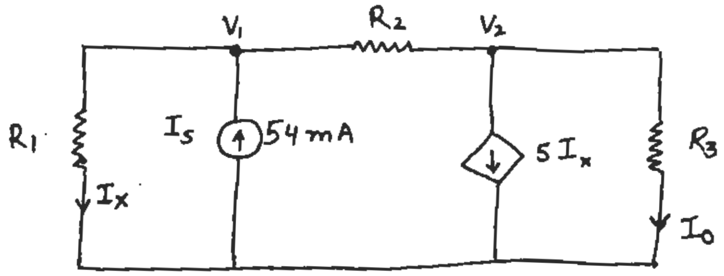


Figure P3.30

SOLUTION: 3.30



$R_1 = R_2 = R_3 = 12\ k\Omega$

KCL @ V_1 : $\frac{V_1}{R_1} - I_s + \frac{V_1 - V_2}{R_2} = 0$

$$\frac{V_1}{12 \times 10^3} - 54 \times 10^{-3} + \frac{V_1 - V_2}{12 \times 10^3} = 0$$

$$2V_1 - V_2 = 648 \quad \text{— ①}$$

$$I_x = \frac{V_1}{R_1}$$

$$I_o = \frac{V_2}{R_3} \quad \text{— ②}$$

KCL @ V_2 : $\frac{V_2 - V_1}{R_2} + 5 I_x + \frac{V_2}{R_3} = 0$

$$\frac{V_2 - V_1}{12 \times 10^3} + 5 \cdot \frac{V_1}{12 \times 10^3} + \frac{V_2}{12 \times 10^3} = 0$$

$$2V_1 + V_2 = 0 \quad \text{—} \quad (3)$$

From equations (1) and (3), we get

$$V_2 = -324\ V$$

Substituting the value of V_2 in equation (2), we get

$$I_o = \frac{V_2}{R_3}$$

$$\boxed{I_o = -27.0\ mA}$$

3.31 Find V_o in the circuit in Fig. P3.31 using nodal analysis.

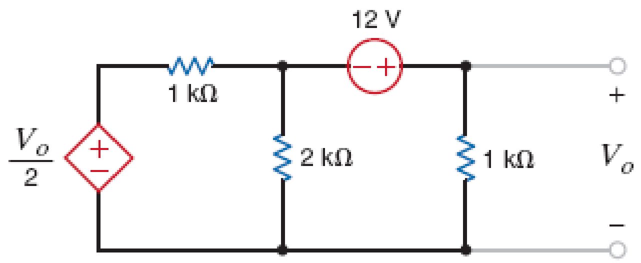
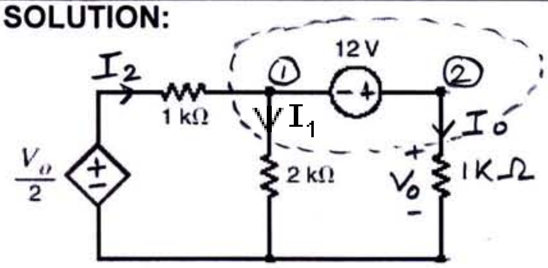


Figure P3.31

SOLUTION:



KCL at supernode: $I_2 = I_1 + I_0$

$$\frac{\frac{V_0}{2} - V_1}{1K} = \frac{V_1}{2K} + \frac{V_2}{1K}$$

$$V_0 = V_2$$

$$\frac{\frac{V_2}{2} - V_1}{1K} = \frac{V_1}{2K} + \frac{V_2}{1K}$$

$$V_2 - 2V_1 = V_1 + 2V_2$$

$$\boxed{3V_1 + V_2 = 0}$$

$$V_2 - V_1 = 12$$

$$\boxed{-V_1 + V_2 = 12}$$

$$3V_1 + V_2 = 0$$
$$-V_1 + V_2 = 12$$

$$V_1 = -3V$$

$$V_2 = 9 \text{ V}$$

$$V_o = V_2 = 9 \text{ V}$$

$$V_o = 9 \text{ V}$$

3.32 Find V_o in the circuit in Fig. P3.32.

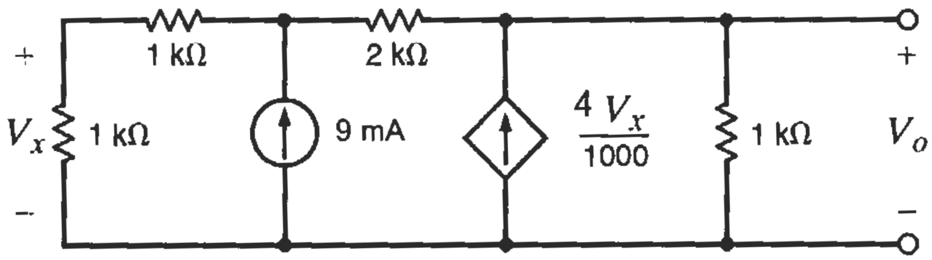
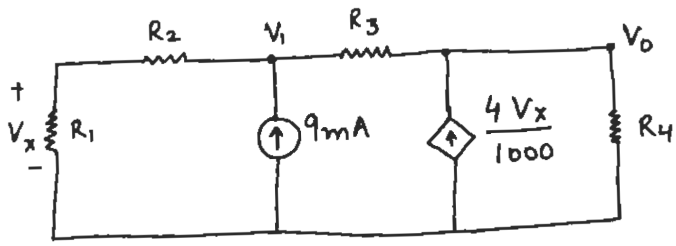


Figure P3.32

SOLUTION: 3.32



$R_1 = R_2 = 1\ k\Omega$, $R_3 = 2\ k\Omega$

KCL @ V_1 : $\frac{V_1}{R_1 + R_2} - 9 \times 10^{-3} + \frac{V_1 - V_o}{R_3} = 0$

$$\frac{V_1}{2 \times 10^3} + \frac{V_1 - V_o}{2 \times 10^3} = 9 \times 10^{-3}$$

$$2V_1 - V_o = 18 \quad \text{— } ①$$

Voltage Division : $V_x = V_1 \frac{R_1}{R_1 + R_2}$

$$V_x = \frac{V_1}{2} \quad \text{— } ②$$

KCL @ V_o : $\frac{-4V_x}{1000} + \frac{V_o - V_1}{R_3} + \frac{V_o}{R_4} = 0$

$$\frac{V_o - V_1}{2 \times 10^3} + \frac{V_o}{1 \times 10^3} = \frac{4V_x}{1000} \quad \text{— } ③$$

Substituting equation ② in ③, we get

$$5V_1 - 3V_o = 0 \quad \text{— } ④$$

From equation ① and ③, we get

$$\boxed{V_o = 90.0\ V}$$

3.33 Use nodal analysis to find V_o in the circuit in Fig. P3.33.

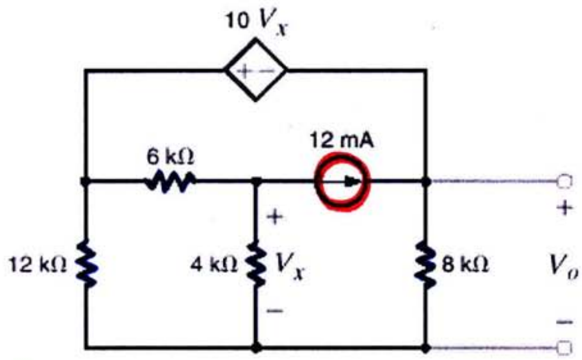
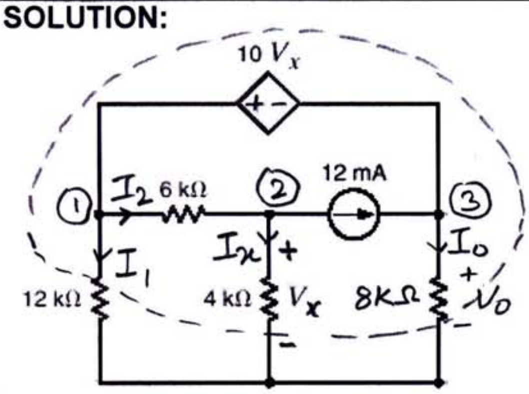


Figure P3.33

SOLUTION:



KCL at supernode : $I_1 + I_x + I_o = 0$

$$\frac{V_1}{12K} + \frac{V_2}{4K} + \frac{V_3}{8K} = 0$$

$$\boxed{2V_1 + 6V_2 + 3V_3 = 0}$$

KCL at 2 : $I_2 = I_x + 12m$

$$\frac{V_1 - V_2}{6K} = \frac{V_2}{4K} + 12m$$

$$2V_1 - 2V_2 = 3V_2 + 144$$

$$\boxed{2V_1 - 5V_2 = 144}$$

$$V_1 - V_3 = 10V_x$$

$$V_x = V_2$$

$$V_1 - V_3 = 10V_2$$

$$\boxed{V_1 - 10V_2 - V_3 = 0}$$

$$2V_1 + 6V_2 + 3V_3 = 0$$
$$2V_1 - 5V_2 + 0V_3 = 144$$
$$V_1 - 10V_2 - V_3 = 0$$

$$V_1 = 150.26 \text{ V}$$
$$V_2 = 31.3 \text{ V}$$
$$V_3 = -162.78 \text{ V}$$

$$V_0 = V_3 = -162.78 \text{ V}$$

$$V_0 = -162.78 \text{ V}$$

3.34 Use nodal analysis to find V_o in the circuit in Fig. P3.34.

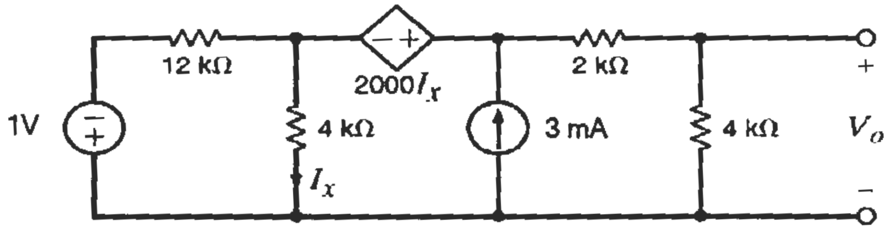
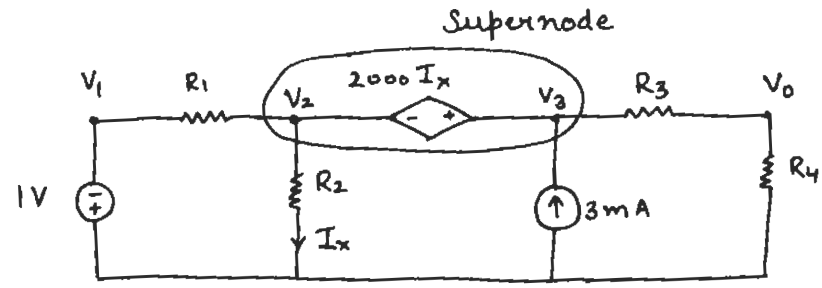


Figure P3.34

SOLUTION: 3.34



$R_1 = 12\ k\Omega$, $R_2 = R_4 = 4\ k\Omega$, $R_3 = 2\ k\Omega$

$$V_1 = -1\ V \quad — \quad (1)$$

$$V_3 - V_2 = 2000 I_x \quad — \quad (2)$$

$$I_x = \frac{V_2}{R_2} = \frac{V_2}{4 \times 10^3} \quad — \quad (3)$$

Substituting equation (3) in (2), we get

$$V_3 - \frac{3}{2} V_2 = 0$$

$$V_2 = \frac{2}{3} V_3 \quad — \quad (4)$$

KCL @ supernode:

$$\frac{V_2 - V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3 - V_o}{R_3} - 3 \times 10^{-3} = 0$$

$$\frac{V_2 - V_1}{12 \times 10^3} + \frac{V_2}{4 \times 10^3} + \frac{V_3 - V_o}{2 \times 10^3} - 3 \times 10^{-3} = 0$$

$$6V_3 + 4V_2 - V_1 - 6V_o = 36 \quad — \quad (5)$$

KCL @ V_o :

$$\frac{V_o}{R_4} + \frac{V_o - V_3}{R_3} = 0$$

$$\frac{V_o}{4 \times 10^3} + \frac{V_o - V_3}{2 \times 10^3} = 0$$

$$3V_o - 2V_3 = 0$$

$$V_3 = \frac{3}{2}V_o \quad \text{—} \quad (6)$$

Substituting equations (1) and (4) in (5), we get

$$26V_3 - 18V_o = 105 \quad \text{—} \quad (7)$$

Substituting equation (6) in (7), we get

$$21V_o = 105$$

$$\boxed{V_o = 5.00\text{ V}}$$

3.35 Determine V_o in the network in Fig. P3.35 using nodal analysis.

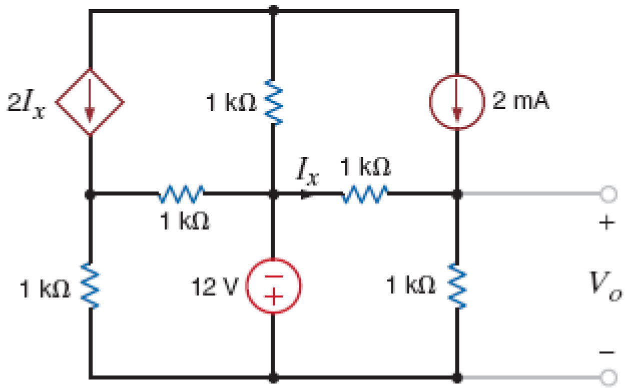
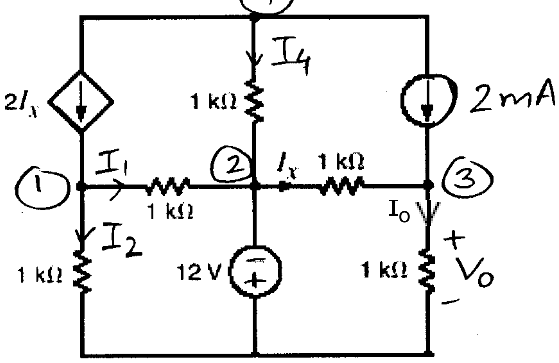


Figure P3.35

SOLUTION:



KCL at 4 : $2I_x + I_4 + 2m = 0$

$$I_x = \frac{V_2 - V_3}{1K}$$

$$2\left[\frac{V_2 - V_3}{1K}\right] + \frac{V_4}{1K} + 2m = 0$$

$$2V_2 - 2V_3 + V_4 + 2 = 0$$

$$\boxed{2V_2 - 2V_3 + V_4 = -2}$$

KCL at ③: $I_x + 2m = I_0$

$$\frac{V_2 - V_3}{1k} + 2m = \frac{V_3}{1k}$$

$$V_2 - V_3 + 2 = V_3$$

$$\boxed{V_2 - 2V_3 = -2}$$

KCL at ①: $2I_x = I_1 + I_2$

$$2\left[\frac{V_2 - V_3}{1K}\right] = \frac{V_1 - V_2}{1K} + \frac{V_1}{1K}$$

$$2V_2 - 2V_3 = V_1 - V_2 + V_1$$

$$\boxed{2V_1 - 3V_2 + 2V_3 = 0}$$

$$V_2 = -12\text{ V}$$

$$-12 - 2V_3 = -2$$

$$-2V_3 = 10$$

$$V_3 = -5\text{ V}$$

$$V_0 = V_3 = -5\text{ V}$$

$$V_0 = -5\text{ V}$$

3.36 Determine V_o in the network in Fig. P3.36.

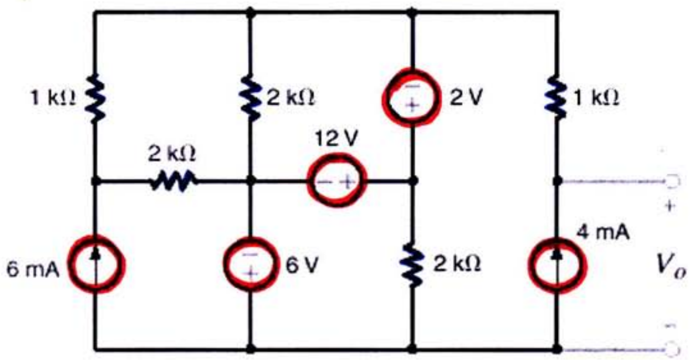
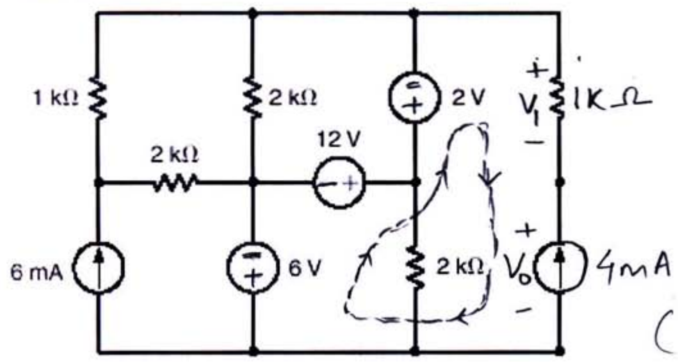


Figure P3.36

SOLUTION:



(Loop indicated by arrows)

$$V_1 = 1K(-4m) = -4V$$

KVL in loop: $12 = 6 + 2 + V_1 + V_o$

$$V_o = 12 - 8 + 4$$

$$V_o = 8\ V$$

3.37 Find I_o in the circuit in Fig. P3.37.

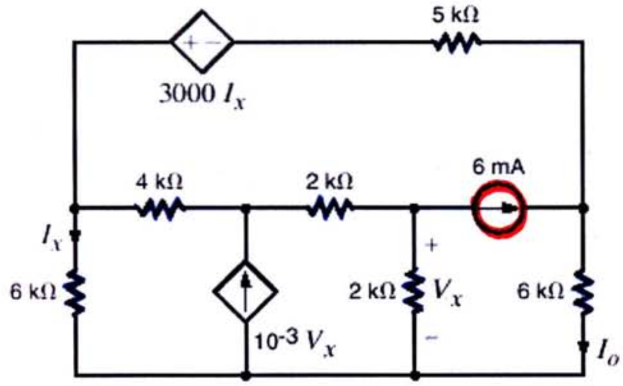
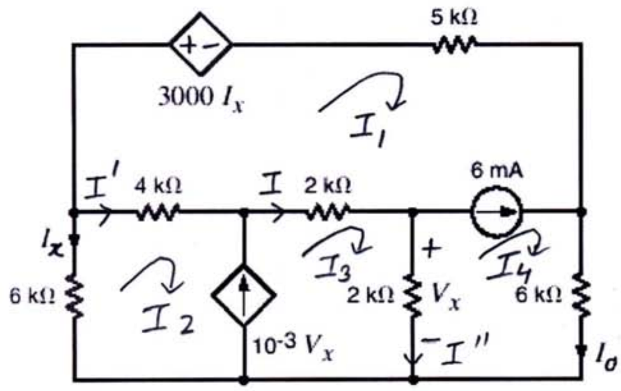


Figure P3.37

SOLUTION:



$$I_2 = -I_x \quad ; \quad I_4 = I_o$$

KCL : $I_2 = I' + I'$

$$I' = I_2 - I_1$$

KCL : $I'' + I_4 = I_3$

$$I'' = I_3 - I_4$$

KCL : $I = I'' + 6m$

$$I = I_3 - I_4 + 6m$$

KCL : $I_3 = 10^{-3} V_x + I_2$

$$-I_2 + I_3 = 10^{-3} V_x$$

$$V_x = 2k\, I''$$

$$V_x = 2k\,(I_3 - I_4)$$

$$-I_2 + I_3 = 10^{-3}(2K)(I_3 - I_4)$$

$$\boxed{I_2 + I_3 - 2I_4 = 0}$$

KCL: $I_1 + 6m = I_4$

$$\boxed{I_1 - I_4 = -6m}$$

KVL: $3000I_x + 5KI_1 + 6KI_4 + 6KI_2 = 0$

$$3000(-I_2) + 5KI_1 + 6KI_4 + 6KI_2 = 0$$

$$\boxed{5KI_1 + 3KI_2 + 6KI_4 = 0}$$

KVL: $4KI' + 2KI + 2KI'' + 6KI_2 = 0$

$$0 = 4K(I_2 - I_1) + 2K(I_3 - I_4 + 6m) + 2K(I_3 - I_4) + 6KI_2$$

$$\boxed{-4KI_1 + 10KI_2 + 4KI_3 - 4KI_4 = -12}$$

$$I_2 + I_3 - 2I_4 = 0$$
$$I_1 - I_4 = -6m$$
$$5KI_1 + 3KI_2 + 6KI_4 = 0$$

$$-4KI_1 + 10KI_2 + 4KI_3 - 4KI_4 = -12$$

$I_1 = -1.64$ mA

$I_2 = -6$ mA

$I_3 = 14.7$ mA

$I_4 = 4.36$ mA

$I_o = I_4$

$I_o = 4.36$ mA

3.38 Use nodal analysis to solve for I_A in the network in Fig. P3.38.

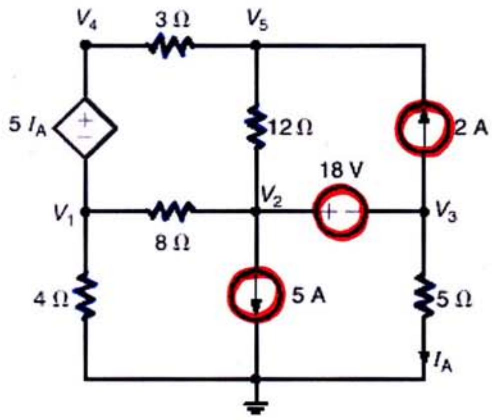
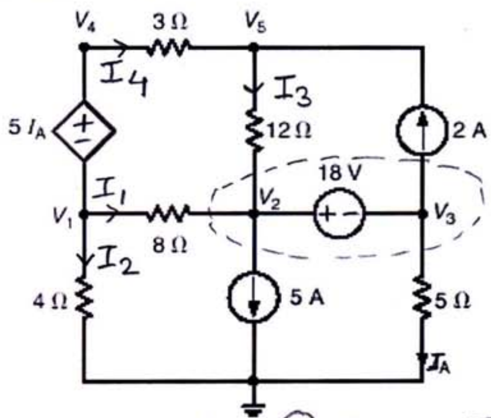


Figure P3.38

SOLUTION:



KCL at 5 : $I_4 + 2 = I_3$

$$\frac{V_4 - V_5}{3} + 2 = \frac{V_5 - V_2}{12}$$

$$4V_4 - 4V_5 + 24 = V_5 - V_2$$

$$\boxed{V_2 + 4V_4 - 5V_5 = -24}$$

KCL at supernode: $I_3 + I_1 = 5 + I_A + 2$

$$\frac{V_5 - V_2}{12} + \frac{V_1 - V_2}{8} = 5 + \frac{V_3}{5} + 2$$

$$5V_5 - 5V_2 + 7.5\,V_1 - 7.5\,V_2 = 300 + 12V_3 + 120$$

$$\boxed{7.5\,V_1 - 12.5\,V_2 - 12V_3 + 5V_5 = 420}$$

$$V_4 - V_1 = 5I_A$$

$$I_A = \frac{V_3}{5}$$

$$V_4 - V_1 = 5(V_3/5)$$

$$V_4 - V_1 = V_3 \quad ; \quad \boxed{-V_1 - V_3 + V_4 = 0}$$

$$\boxed{V_2 - V_3 = 18}$$

KCL at reference: $I_2 + 5 + I_A = 0$

$$\frac{V_1}{4} + 5 + \frac{V_3}{5} = 0$$

$$5V_1 + 100 + 4V_3 = 0$$

$$\boxed{5V_1 + 4V_3 = -100}$$

$$0V_1 + V_2 + 0V_3 + 4V_4 - 5V_5 = -24$$

$$7.5V_1 - 12.5V_2 - 12V_3 + 0V_4 + 5V_5 = 420$$

$$-V_1 + 0V_2 - V_3 + V_4 + 0V_5 = 0$$

$$0V_1 + V_2 - V_3 + 0V_4 + 0V_5 = 18$$

$$5V_1 + 0V_2 + 4V_3 + 0V_4 + 0V_5 = -100$$

$$V_1 = 3.22 \text{ V}$$

$$V_2 = -11.02 \text{ V}$$

$$V_3 = -29.02 \text{ V}$$

$$V_4 = -25.81 \text{ V}$$

$$V_5 = -18.05 \text{ V}$$

$$I_A = \frac{V_3}{5} = \frac{-29.02}{5}$$

$$I_A = -5.8 \text{ A}$$

3.39 Use nodal analysis to find V_1, V_2, V_3, and V_4 in the circuit in Fig. P3.39.

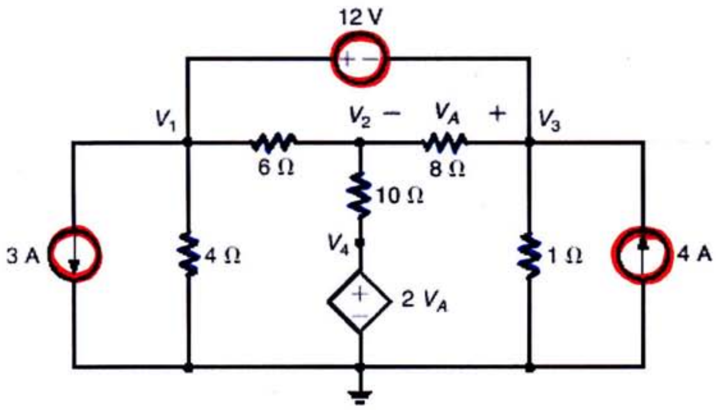
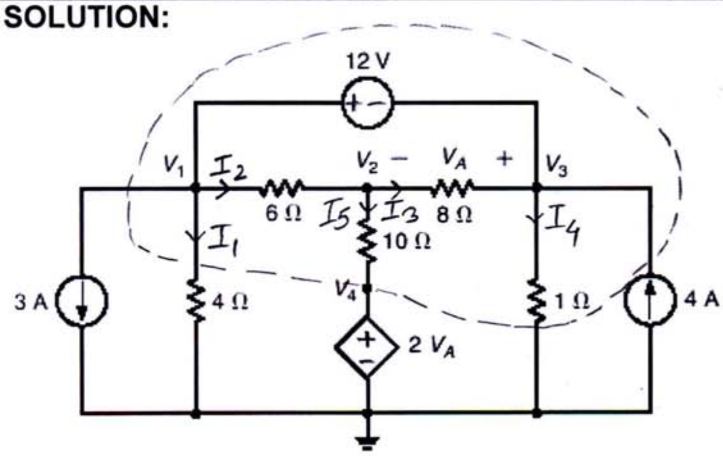


Figure P3.39

SOLUTION:



KCL at ②: $I_2 = I_5 + I_3$

$$\frac{V_1 - V_2}{6} = \frac{V_2 - V_4}{10} + \frac{V_2 - V_3}{8}$$

$$5V_1 - 5V_2 = 3V_2 - 3V_4 + 3.75V_2 - 3.75V_3$$

$$\boxed{5V_1 - 11.75V_2 + 3.75V_3 + 3V_4 = 0}$$

KCL at supernode: $3 + I_1 + I_5 + I_4 = 4$

$$\frac{V_1}{4} + \frac{V_2 - V_4}{10} + \frac{V_3}{1} = 1$$

$$5V_1 + 2V_2 - 2V_4 + 20V_3 = 20$$

$$\boxed{5V_1 + 2V_2 + 20V_3 - 2V_4 = 20}$$

$$V_1 - V_3 = 12$$

$$V_4 = 2V_A$$

$$V_A = V_3 - V_2$$

$$V_4 = 2(V_3 - V_2) \qquad \boxed{-2V_2 + 2V_3 - V_4 = 0}$$

$$5V_1 - 11.75V_2 + 3.75V_3 + 3V_4 = 0$$

$$5V_1 + 2V_2 + 20V_3 - 2V_4 = 20$$

$$V_1 + 0V_2 - V_3 + 0V_4 = 12$$

$$0V_1 - 2V_2 + 2V_3 - V_4 = 0$$

$$V_1 = 9.68\ V$$

$$V_2 = 1.45\ V$$

$$V_3 = -2.32\ V$$

$$V_4 = -7.54\ V$$

3.40 Use nodal analysis to find V_1, V_2, V_3, and V_4 in the network in Fig. P3.40

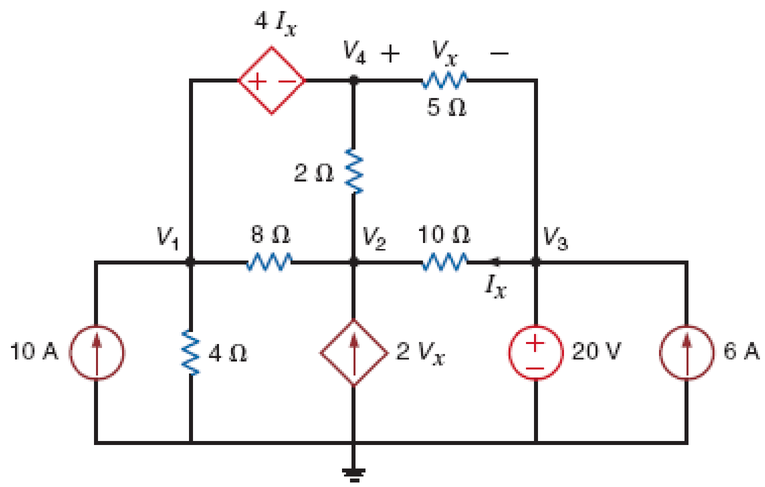
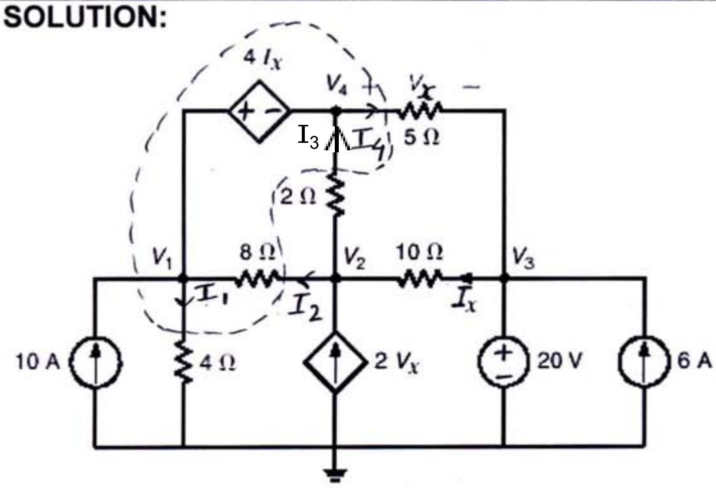


Figure P3.40

SOLUTION:



KCL at 2 : $2V_x + I_x = I_2 + I_3$

$$V_x = V_4 - V_3$$

$$2(V_4 - V_3) + \frac{V_3 - V_2}{10} = \frac{V_2 - V_1}{8} + \frac{V_2 - V_4}{2}$$

$$80V_4 - 80V_3 + 4V_3 - 4V_2 = 5V_2 - 5V_1 + 20V_2 - 20V_4$$

$$\boxed{5V_1 - 29V_2 - 76V_3 + 100V_4 = 0}$$

$$V_3 = 20\text{V}$$

$$\boxed{5V_1 - 29V_2 + 100V_4 = 1520}$$

KCL at supernode : $10 + I_2 + I_3 = I_1 + I_4$

$$10 + \frac{V_2 - V_1}{8} + \frac{V_2 - V_4}{2} = \frac{V_1}{4} + \frac{V_4 - V_3}{5}$$

$$400 + 5V_2 - 5V_1 + 20V_2 - 20V_4 = 10V_1 + 8V_4 - 8V_3$$

$$\boxed{-15V_1 + 25V_2 + 8V_3 - 28V_4 = -400}$$

$$\boxed{-15V_1 + 25V_2 - 28V_4 = -560}$$

$$V_1 - V_4 = 4I_x$$

$$I_x = \frac{V_3 - V_2}{10}$$

$$V_1 - V_4 = 4\left(\frac{V_3 - V_2}{10}\right)$$

$$10V_1 - 10V_4 = 4V_3 - 4V_2$$

$$\boxed{10V_1 + 4V_2 - 4V_3 - 10V_4 = 0}$$

$$\boxed{10V_1 + 4V_2 - 10V_4 = 80}$$

$$5V_1 - 29V_2 + 100V_4 = 1520$$

$$-15V_1 + 25V_2 - 28V_4 = -560$$

$$10V_1 + 4V_2 - 10V_4 = 80$$

$$V_1 = 21.14\ \text{V}$$

$$V_2 = 9.07\ \text{V}$$

$$V_4 = 16.77\ \text{V}$$

$$V_3 = 20\ \text{V}$$

3.41 Find I_o in the network in Fig. P3.41 using nodal analysis.

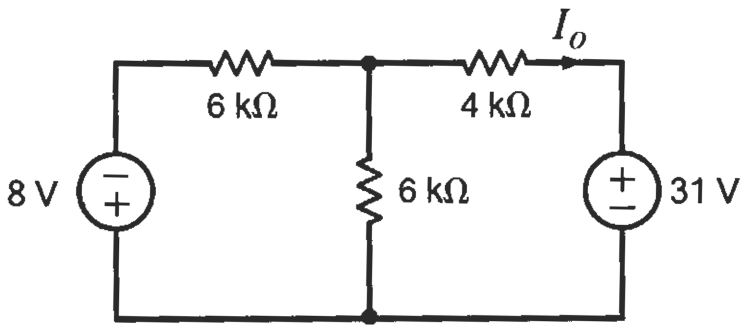
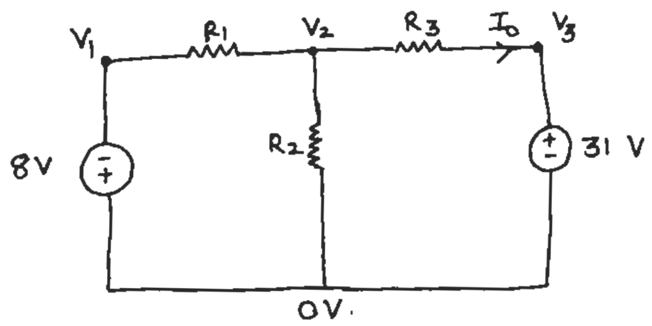


Figure P3.41

SOLUTION: 3.41



$R_1 = R_2 = 6\,k\Omega,\quad R_3 = 4\,k\Omega\quad, I_o = \dfrac{V_2 - V_3}{R_3}$ — ①

@ V_1 : $V_1 = -8\,V$ — ②

KCL @ V_2 : $\dfrac{V_2 - V_1}{R_1} + \dfrac{V_2}{R_2} + \dfrac{V_2 - V_3}{R_3} = 0$

$$\frac{V_2 - V_1}{6\times10^3} + \frac{V_2}{6\times10^3} + \frac{V_2 - V_3}{4\times10^3} = 0$$

$7V_2 - 3V_3 - 2V_1 = 0$ — ③

@ V_3 : $V_3 = 31\,V$ — ④

Substituting equations ④ and ② in ③, we get

$7V_2 - 3V_3 - 2V_1 = 0$

$7V_2 - 3(31) - 2(-8) = 0$

$V_2 = 11\,V$ — ⑤

Substituting equations 4 and 5 in 1, we get

$$I_o = \frac{V_2 - V_3}{R_3}$$

$$\boxed{I_o = -5.00 \text{ mA}}$$

3.42 Use nodal analysis to find V_o in the circuit in Fig. P3.42.

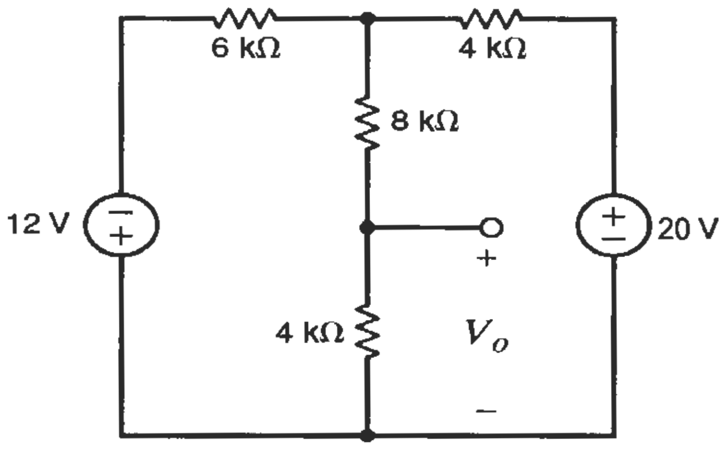
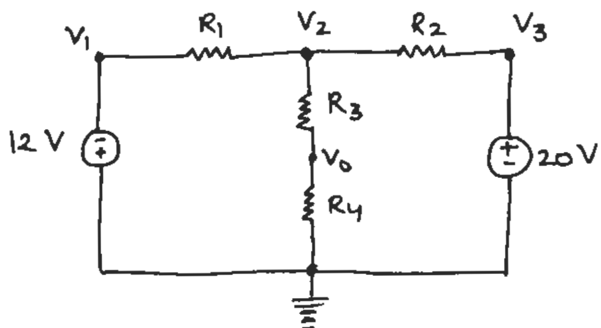


Figure P3.42

SOLUTION: 3.42



$R_1 = 6\ k\Omega$, $R_2 = R_4 = 4\ k\Omega$, $R_3 = 8\ k\Omega$

$V_1 = -12\ V$; $V_3 = 20\ V$

KCL @ V_2 : $\dfrac{V_2 - V_1}{R_1} + \dfrac{V_2 - V_o}{R_3} + \dfrac{V_2 - V_3}{R_2} = 0$

$$\frac{V_2 + 12}{6 \times 10^3} + \frac{V_2 - V_o}{8 \times 10^3} + \frac{V_2 - 20}{4 \times 10^3} = 0$$

$$\Rightarrow \quad 13 V_2 - 3 V_o = 72 \quad \text{——} \quad (1)$$

KCL @ V_o : $\dfrac{V_o}{R_4} + \dfrac{V_o - V_2}{R_3} = 0$

$$\frac{V_o}{4 \times 10^3} + \frac{V_o - V_2}{8 \times 10^3} = 0$$

$$\Rightarrow \quad 3 V_o - V_2 = 0 \quad \text{——} \quad (2)$$

From equations ① and ②, we get

$$12 V_2 = 72$$

$$V_2 = 6 \text{ V}$$

Substituting the value of V_2 in equation ②, we get

$$3V_0 - V_2 = 0$$

$$\boxed{V_0 = 2.00 \text{ V}}$$

3.43 Find I_o in the circuit in Fig. P3.43.

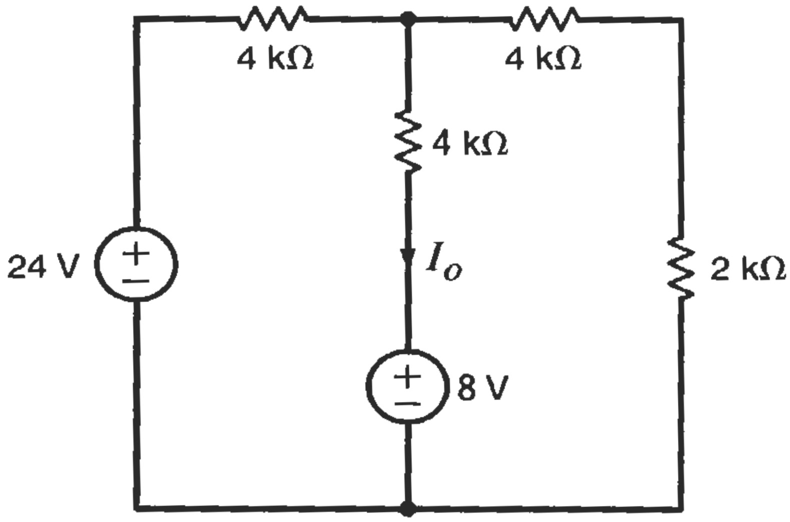
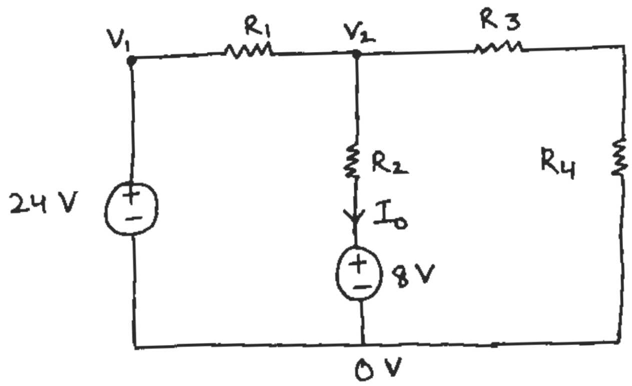


Figure P3.43

SOLUTION: 3.43



$R_1 = R_2 = R_3 = 4\,k\Omega$, $R_4 = 2\,k\Omega$

@ V_1 : $V_1 = 24\ V$ — ①

KCL @ V_2 : $\dfrac{V_2 - V_1}{R_1} + \dfrac{V_2 - 8}{R_2} + \dfrac{V_2}{R_3 + R_4} = 0$

$$\frac{V_2 - V_1}{4 \times 10^3} + \frac{V_2 - 8}{4 \times 10^3} + \frac{V_2}{6 \times 10^3} = 0$$

$\Rightarrow 8 V_2 - 3 V_1 = 24$ — ②

Substituting equation ① in ②, we get

$$8 V_2 - 3 V_1 = 24$$

$$\Rightarrow V_2 = 12\text{ V}$$

$$I_O = \frac{V_2 - 8}{R_2}$$

$$\boxed{I_O = 1.00\text{ mA}}$$

3.44 Find V_o in the network in Fig. P3.44 using mesh equations.

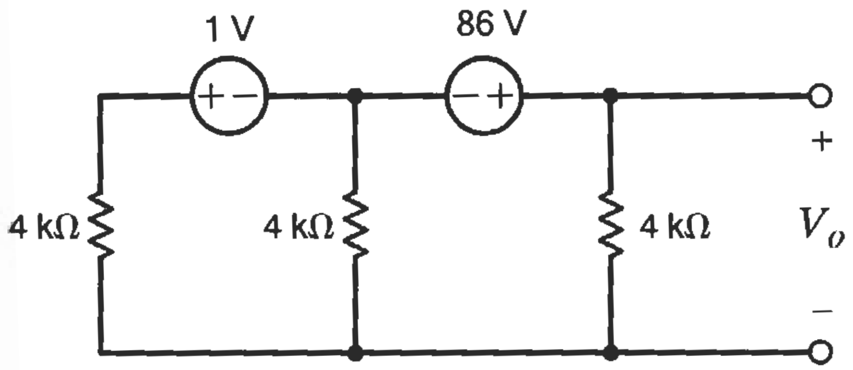
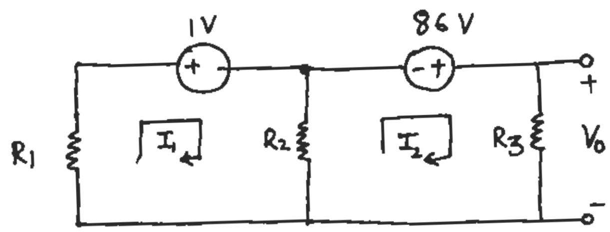


Figure P3.44

SOLUTION: 3.44



$R_1 = R_2 = R_3 = 4\ k\Omega$

KVL @ I_1 : $I_1 R_1 + 1 + (I_1 - I_2) R_2 = 0$

$$I_1 (4\times10^3) + (I_1 - I_2)(4\times10^3) = -1$$

$$8 I_1 - 4 I_2 = -1 \times 10^{-3} \quad \text{——— (1)}$$

KVL @ I_2 : $(I_2 - I_1) R_2 - 86 + I_2 R_3 = 0$

$$(I_2 - I_1)(4\times10^3) + I_2 (4\times10^3) = 86$$

$$-8 I_1 + 16 I_2 = 172 \times 10^{-3} \quad \text{——— (2)}$$

From equations (1) and (2), we get

$$12 I_2 = 171 \times 10^{-3}$$

$$I_2 = \frac{171}{12} \times 10^{-3}\ A$$

$$V_o = I_2 R_3$$

$$= \frac{171}{12} \times 10^{-3} \times 4 \times 10^{3}$$

$$\boxed{V_o = 57.0V}$$

3.45 Find V_o in the network in Fig. P3.45 using mesh equations.

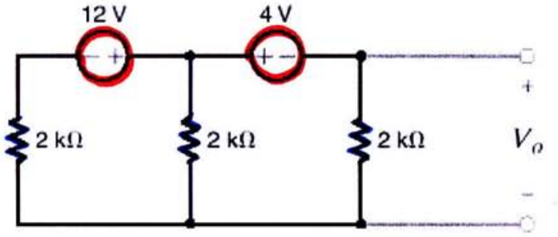
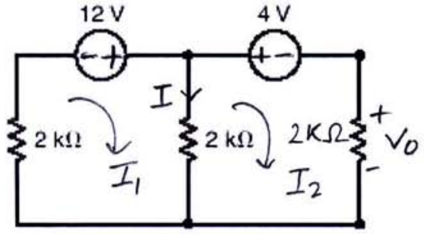


Figure P3.45

SOLUTION:



$$I_1 = I + I_2$$
$$I = I_1 - I_2$$

KVL left loop: $12 = 2KI_1 + 2KI$

$$2KI_1 + 2K(I_1 - I_2) = 12$$

$$\boxed{4KI_1 - 2KI_2 = 12}$$

KVL right loop: $4 + 2KI_2 + 2K(-I) = 0$

$$2KI_2 - 2K(I_1 - I_2) = -4$$

$$\boxed{-2KI_1 + 4KI_2 = -4}$$

$$4KI_1 - 2KI_2 = 12$$
$$-2KI_1 + 4KI_2 = -4$$

$I_1 = 3.333$ mA ; $I_2 = 0.667$ mA

$V_0 = I_2(2K) = 0.667m(2K)$

$V_0 = 1.33$ V

3.46 Find I_o in the circuit in Fig. P3.46.

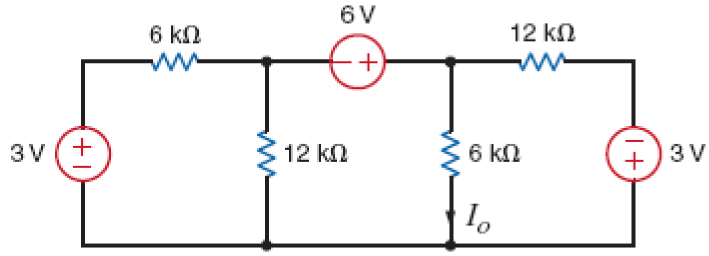
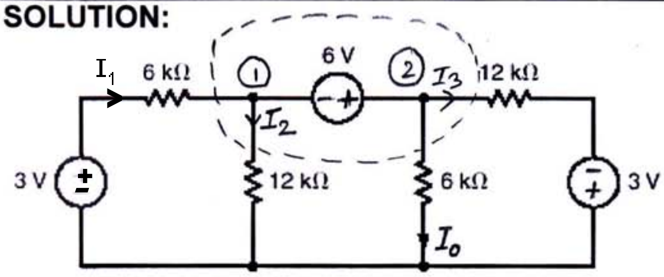


Figure P3.46

SOLUTION:



KCL at supernode : $I_1 = I_2 + I_o + I_3$

$$\frac{3-V_1}{6K} = \frac{V_1}{12K} + \frac{V_2}{6K} + \frac{V_2-(-3)}{12K}$$

$$6 - 2V_1 = V_1 + 2V_2 + V_2 + 3$$

$$\boxed{3V_1 + 3V_2 = 3}$$

$$V_2 - V_1 = 6$$

$$\boxed{-V_1 + V_2 = 6}$$

$$3V_1 + 3V_2 = 3$$
$$-V_1 + V_2 = 6$$

$$V_1 = -2.5 \text{ V}$$
$$V_2 = 3.5 \text{ V}$$

$$I_o = \frac{V_2}{6K} = \frac{3.5}{6K}$$

$$I_o = 0.5833 \text{ mA}$$

3.47 Find V_o in the circuit in Fig. P3.47 using nodal analysis.

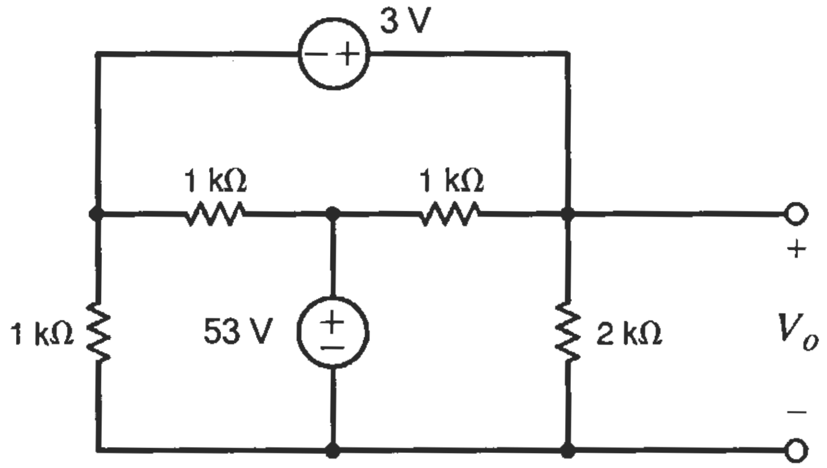
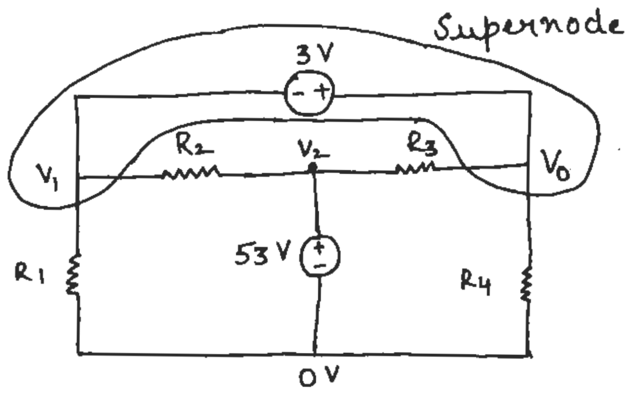


Figure P3.47

SOLUTION: 3.47



$R_1 = R_2 = R_3 = 1\,k\Omega$, $R_4 = 2\,k\Omega$

$V_o - V_1 = 3\,V$ — ① $V_2 = 53\,V$

KVL @ supernode,

$$\frac{V_1}{R_1} + \frac{V_1 - V_2}{R_2} + \frac{V_o}{R_4} + \frac{V_o - V_2}{R_3} = 0$$

$$4V_1 + 3V_o = 212 \quad \text{——} \quad ②$$

Substituting equation ① in ②, we get

$$4(V_o - 3) + 3V_o = 212$$

$$\boxed{V_o = 32.0\,V}$$

3.48 Solve Problem 3.23 using loop analysis.

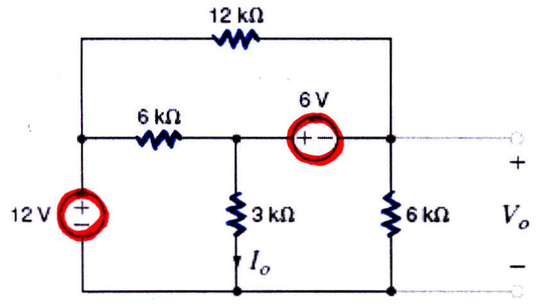
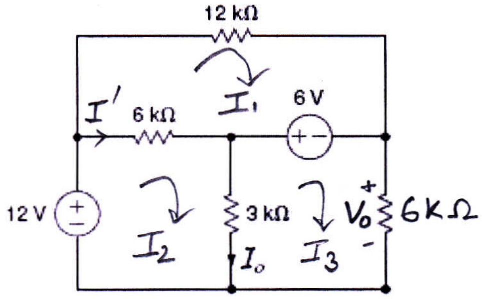


Figure P3.23

SOLUTION:



KCL: $I_2 = I' + I_1$

$I' = I_2 - I_1$

KVL: $\boxed{12KI_1 + 6KI_3 = 12}$

KCL: $I_0 + I_3 = I_2$

$I_0 = I_2 - I_3$

KVL: $6 + 6kI_3 + 3K(-I_0) = 0$

$6 + 6KI_3 - 3K(I_2 - I_3) = 0$

$\boxed{-3KI_2 + 9KI_3 = -6}$

KVL: $12 = 6KI + 6 + 6KI_3$

$6K(I_2 - I_1) + 6KI_3 = 6$

$\boxed{-6KI_1 + 6kI_2 + 6KI_3 = 6}$

$$12KI_1 + 0I_2 + 6KI_3 = 12$$
$$0I_1 - 3KI_2 + 9KI_3 = -6$$
$$-6KI_1 + 6KI_2 + 6KI_3 = 6$$

$$I_1 = 1\ mA$$

$$I_2 = 2\ mA$$

$$I_3 = 0\ A$$

$$V_o = 6K I_3$$

$$V_o = 6K(0)$$

$$V_o = 0\ V$$

3.49 Solve Problem 3.27 using loop analysis.

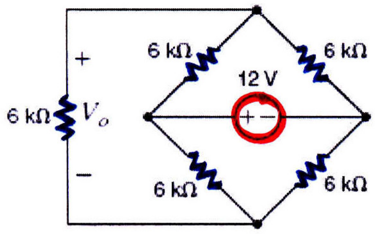
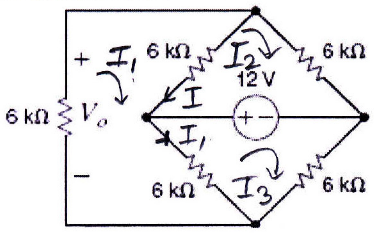


Figure P3.27

SOLUTION:



KCL : $I_1 = I + I_2$

$I = I_1 - I_2$

KCL : $I' + I_3 = I_1$

$I' = I_1 - I_3$

KVL : $\boxed{6KI_1 + 6KI_2 + 6KI_3 = 0}$

KVL : $12 = 6K(-I) + 6KI_2$

$-6K(I_1 - I_2) + 6KI_2 = 12$

$\boxed{-6KI_1 + 12KI_2 = 12}$

$6KI_1 + 6KI_2 + 6KI_3 = 0$

$18KI_1 - 6KI_2 - 6KI_3 = 0$

$-6KI_1 + 12KI_2 + 0I_3 = 12$

$I_1 = 0\ A$

$I_2 = 1\ mA$

$I_3 = -1\ mA$

$V_o = -I_1(6K)$

$V_o = 0\ V$

3.50 Use loop analysis to find V_o in the network in Fig. P3.50.

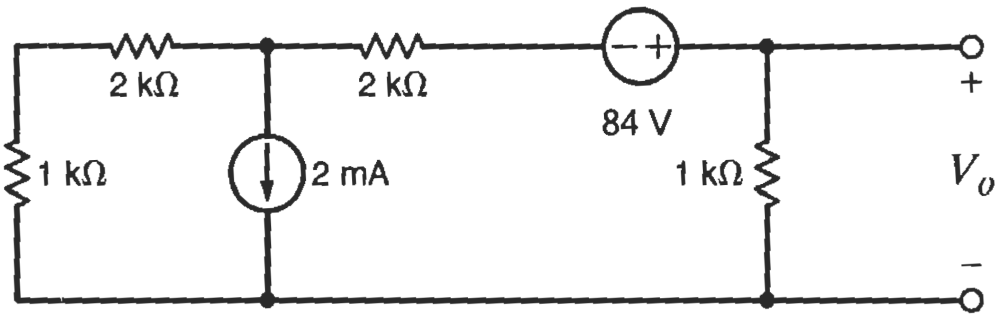
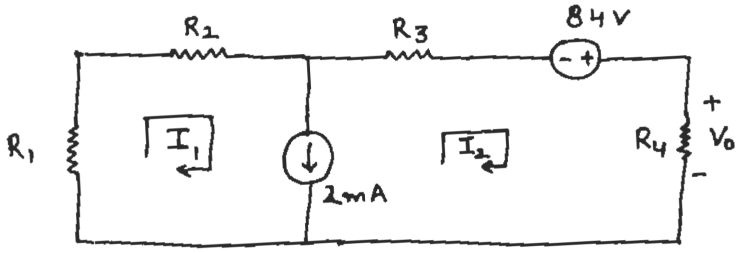


Figure P3.50

SOLUTION: 3.50



$R_1 = R_4 = 1\,k\Omega$, $R_2 = R_3 = 2\,k\Omega$

$V_0 = I_2 R_4$

$I_1 - I_2 = 2 \times 10^{-3}\,A$ ——— ①

$I_1 R_1 + I_1 R_2 + I_2 R_3 - 84 + I_2 R_4 = 0$

$I_1 (R_1 + R_2) + I_2 (R_3 + R_4) = 84$

$(3 \times 10^3) I_1 + (3 \times 10^3) I_2 = 84$

$I_1 + I_2 = 28 \times 10^{-3}$ ——— ②

From equations ① and ②, we get

$2 I_1 = 30 \times 10^{-3}$

$I_1 = 15\,mA$ and $I_2 = 13\,mA$

$V_0 = I_2 R_4$

$= 13 \times 10^{-3} \times 1 \times 10^3$

$\boxed{V_0 = 13.0\,V}$

3.51 Use mesh analysis to find V_o in the network in Fig. P3.51.

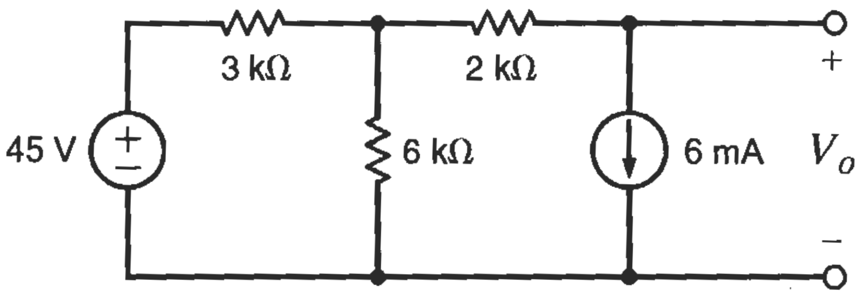
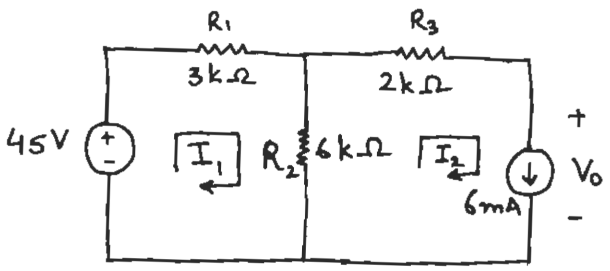


Figure P3.51

SOLUTION: 3.51



$I_2 = 6\,mA$

KVL @ I_1 : $-45 + I_1R_1 + (I_1 - I_2)R_2 = 0$

$$I_1(R_1 + R_2) - I_2R_2 = 45$$

$$9\times10^3(I_1) - 6\times10^3(I_2) = 45$$

$$I_1 = 9\times10^{-3}$$

$$= 9\,mA$$

KVL @ I_2 : $-45 + I_1R_1 + I_2R_3 + V_o = 0$

$$-45 + [9\times10^{-3}\times3\times10^3] + [(6\times10^{-3})\times(2\times10^3)] + V_o = 0$$

$$\boxed{V_o = 6.00\ V}$$

3.52 Find I_o in the circuit in Fig. P3.52 using mesh analysis.

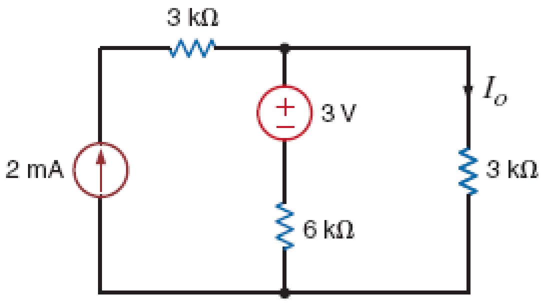
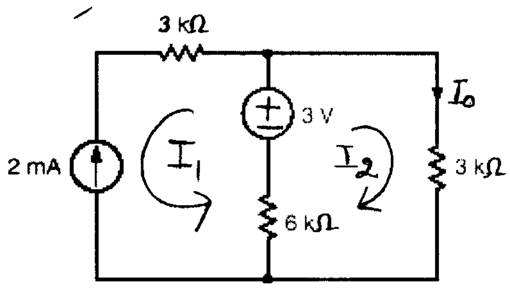


Figure P3.52

SOLUTION:



Let the loop currents be I_1 & I_2 mA

From loop 1 :

$$I_1 = -2 \text{ mA} \quad — (1)$$

Applying KVL in second loop :

$$3 = 3I_2 + 6(I_1 + I_2)$$

$$\Rightarrow 3 = 9I_2 + 6I_1 \quad — (2)$$

From equation (1) & (2)

$$3 = 9(I_2) + 6I_1 = 9I_2 + 6(-2)$$

$$\Rightarrow \quad I_2 = \frac{15}{9}$$

$$\Rightarrow \quad I_2 = \frac{5}{3} = 1.667 \text{ mA}$$

$$I_0 = I_2 = 1.67 \text{ mA}$$

3.53 Find V_o in the circuit in Fig. P3.53 using mesh analysis.

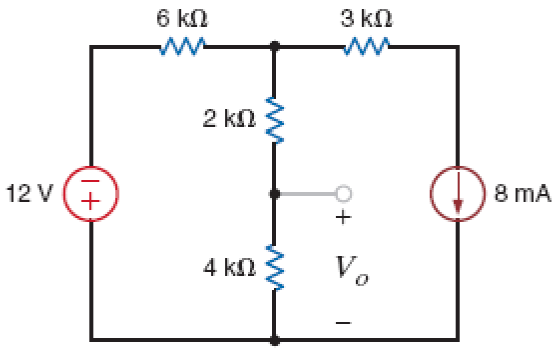
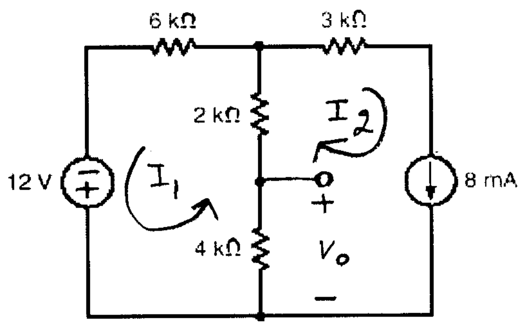


Figure P3.53

SOLUTION:



Let I_1 & I_2 be two loop currents in mA.

From loop 2 :

$$I_2 = 8 \text{ mA} \quad — (1)$$

KVL in the loop 1 :

$$12 = 4(I_1 + I_2) + 2(I_1 + I_2) + 6I_1$$

$$\Rightarrow 12 = 12I_1 + 6I_2 \quad — (2)$$

Substituting the value of I_2 from ① in ②

$$\Rightarrow \quad 12 = 12I_1 + 6(8)$$

$$\Rightarrow \quad I_1 = -3\,mA \quad — ③$$

$$V_0 = -4 \times (I_1 + I_2)$$

$$\Rightarrow \quad V_0 = -4(-3+8)$$

$$\Rightarrow \quad V_0 = -4(5)$$

$$V_0 = -20 \text{ Volts}$$

3.54 Use mesh analysis to find V_o in the circuit in Fig. P3.54.

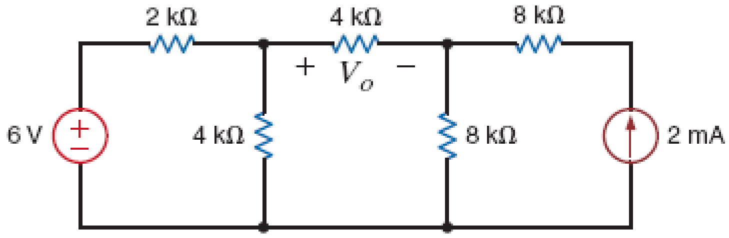
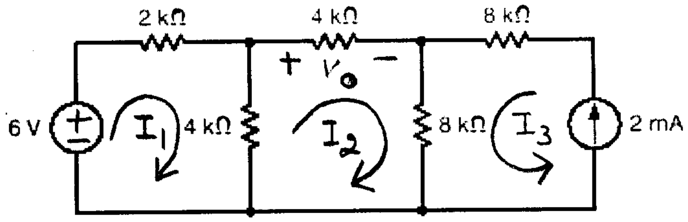


Figure P3.54

SOLUTION:



Let the loop currents be I_1, I_2 and I_3 mA as shown in the diagram.

KVL in the first loop gives :

$$6 = 2I_1 + 4(I_1 - I_2)$$

$$\Rightarrow 6 = 6I_1 - 4I_2 \quad — (1)$$

KVL in the second loop gives :

$$0 = 4(I_2 - I_1) + 4I_2 + 8(I_2 + I_3)$$

$$\Rightarrow 0 = 16I_2 - 4I_1 + 8I_3 \quad — (2)$$

From the third loop:

$$I_3 = 2\,mA \quad — (3)$$

From equation (2) & (3)

$$0 = 16I_2 - 4I_1 + 8(2)$$

$$\Rightarrow 16 = 4I_1 - 16I_2 \quad — (4)$$

$$\Rightarrow 4 = I_1 - 4I_2$$

$$6 = 6I_1 - 4I_2 \quad — (1)$$

Solving these two equations

$$2 = 5I_1 \qquad \therefore I_1 = \frac{2}{5} = 0.4\,mA$$

$$I_2 = -0.9\,mA$$

$$V_o = I_2 \times 4K = 4 \times (-0.9) = -3.6 \text{ Volts.}$$

3.55 Use mesh analysis to find I_o in the network in Fig. P3.55.

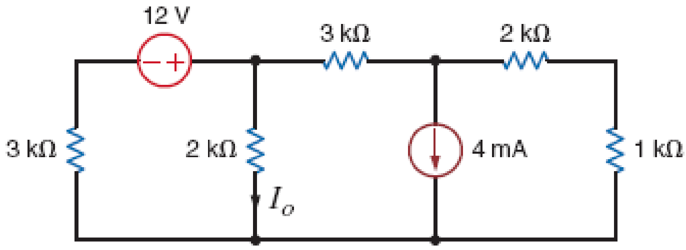
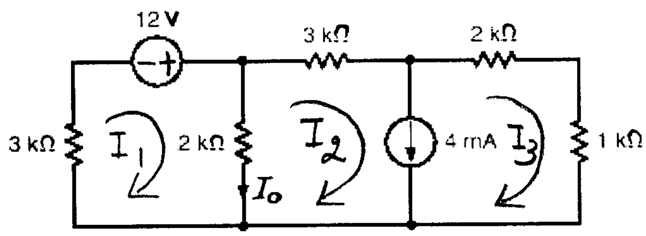


Figure P3.55

SOLUTION:



Let I_1, I_2 and I_3 be the loop currents (in mA) as shown in the diagram.

KVL in the first loop:

$$12 = 2(I_1 - I_2) + 3I_1$$

$$\Rightarrow 12 = 5I_1 - 2I_2 \quad \text{——— (1)}$$

From the second loop:

$$I_2 - I_3 = 4 \quad \text{——— (2)}$$

KVL in the loop outer to loop 2 & 3

$$0 = 3I_2 + 2I_3 + I_3 + 2(I_2 - I_1)$$

$$\Rightarrow 0 = 5I_2 + 3I_3 - 2I_1 \quad \text{——} \quad (3)$$

upon solving these three equations, we get

$$I_1 = \frac{10}{3}\,mA, \quad I_2 = \frac{7}{3}\,mA, \quad I_3 = -\frac{5}{3}\,mA$$

$$I_o = I_1 - I_2$$

$$\Rightarrow I_o = \frac{10}{3} - \frac{7}{3} = \frac{3}{3} = 1\,mA$$

$$\boxed{I_o = 1\,mA}$$

3.56 Find I_o in the network in Fig. P3.56 using loop analysis.

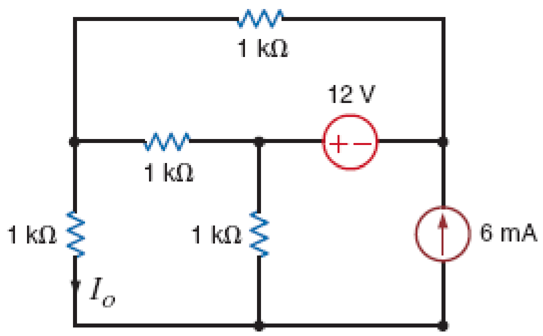
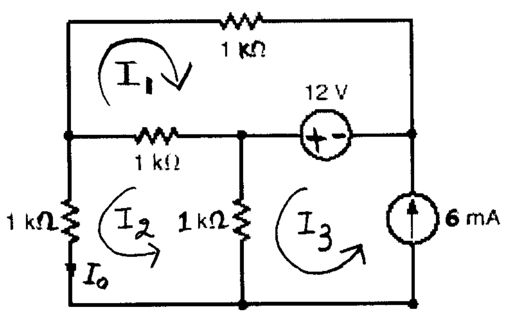


Figure P3.56

SOLUTION:



Let I_1, I_2 and I_3 be the loop currents (in mA).

KVL in the first loop:

$$12 = 1(I_1 + I_2) + 1 \times I_1$$

$$\Rightarrow 12 = 2I_1 + I_2 \quad \text{— (1)}$$

From the third loop:

$$I_3 = 6 \text{ mA} \quad \text{— (2)}$$

KVL in the second loop:

$$1(I_1 + I_2) + 1(I_2) + 1(I_2 - I_3) = 0$$

$$\Rightarrow I_1 + 3I_2 - I_3 = 0 \quad \text{—} \quad (3)$$

From equation (2) & (3), we get :

$$I_1 + 3I_2 = I_3 = 6 \quad \text{—} \quad (4)$$

From equation (1) & (4) :

$$12 = 2I_1 + I_2 \quad \text{—} \quad (1)$$

$$6 = I_1 + 3I_2$$

$$\Rightarrow 12 = 2I_1 + 6I_2 \quad \text{—} \quad (5)$$

$$5I_2 = 0 \quad \{ eq.(5) - eq.(1) \}$$

Or $\boxed{I_2 = 0mA}$

3.57 Use loop analysis to find I_o and I_1 in the network in Fig. P3.57.

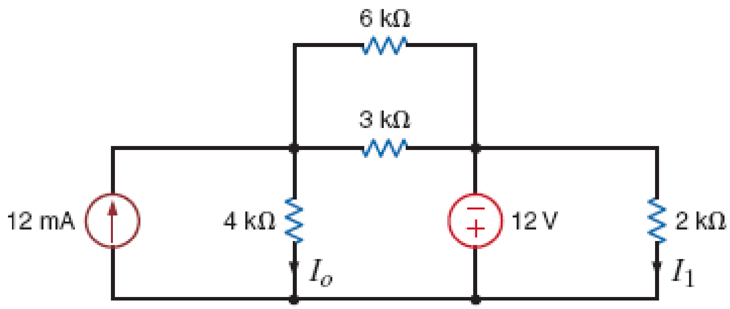
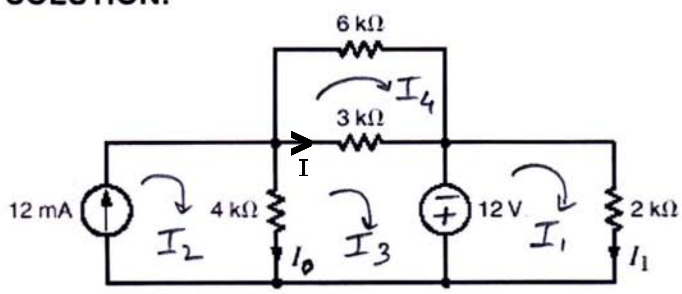


Figure P3.57

SOLUTION:



$$I_2 = 12\ mA$$

KCL : $I_o + I_3 = I_2$

$$I_o = I_2 - I_3$$

KCL : $I_2 = I + I_o + I_4$

$$I = I_2 - I_2 + I_3 - I_4$$

$$I = I_3 - I_4$$

KVL: $12 = -2k I_1$

$$I_1 = -6\ mA$$

KVL: $12 = 4k(-I_o) + 6k I_4$

$$-4k(-I_o) + 6k I_4$$

$$-4k(I_2 - I_3) + 6k I_4 = 12$$

$$-4k I_2 + 4k I_3 + 6k I_4 = 12$$

$$\boxed{4k I_3 + 6k I_4 = 60}$$

KVL: $12 = 4K(-I_0) + 3K I$.

$-4K(I_2 - I_3) + 3K(I_3 - I_4) = 12$

$$\boxed{7I_3 - 4I_2 - 3I_4 = 12}$$

KVL: $6k I_4 + 3k(I_4 - I_3) = 0$

$I_4 = I_3 | 3$

$I_3 = 10mA$

$I_4 = 3.33mA$

$I_0 = I_2 - I_3 = 12m - 10m = 2mA$

$I_0 = 2mA$

3.58 Find I_o in the network in Fig. P3.58 using loop analysis. Then solve the problem using MATLAB and compare your answers.

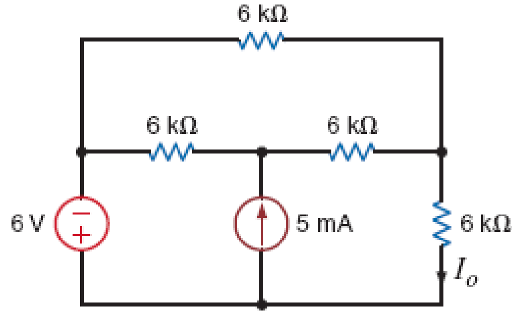
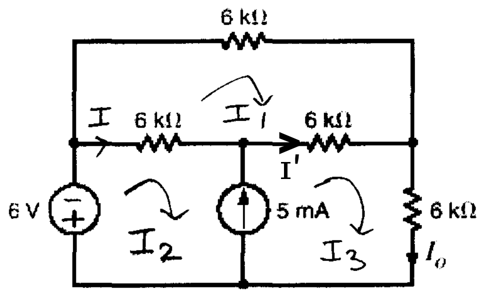


Figure P3.58

SOLUTION:



$$I_3 = I_o$$

KCL: $I_2 = I + I_1$

$$I = I_2 - I_1$$

KCL; $I_1 + I' = I_3$

$$I' = I_3 - I_1$$

KVL; KVL in the top loop:

$$18 I_1 - 6 I_2 - 6 I_3 = 0$$

$$\boxed{3I_1 - I_2 - I_3 = 0}$$

KVL: $6 + 6kI + 6kI' + 6kI_o = 0$

$$6k(I_2 - I_1) + 6k(I_3 - I_1) + 6kI_3 = -6$$

$$\boxed{-12kI_1 + 6kI_2 + 12kI_3 = -6} \Rightarrow \boxed{2I_1 - I_2 - 2I_3 = 1}$$

KCL: $I_3 = 5m + I_2$

$$\boxed{-I_2 + I_3 = 5m}$$

upon solving these equations we get, $i_3 = 2/5 = 0.4$ mA

```
% MATLAB Code and Solution for Problem 3.65

R = [3,-1,-1; 2,-1,-2; 0,-2,1];

V = [0; 1; 5]

Imatrix = inv(R) * V

>>
Imatrix =

   -0.0016
   -0.0044
    0.0006
```

3.59 Use nodal analysis to find V_o in the circuit in Fig. P3.59.

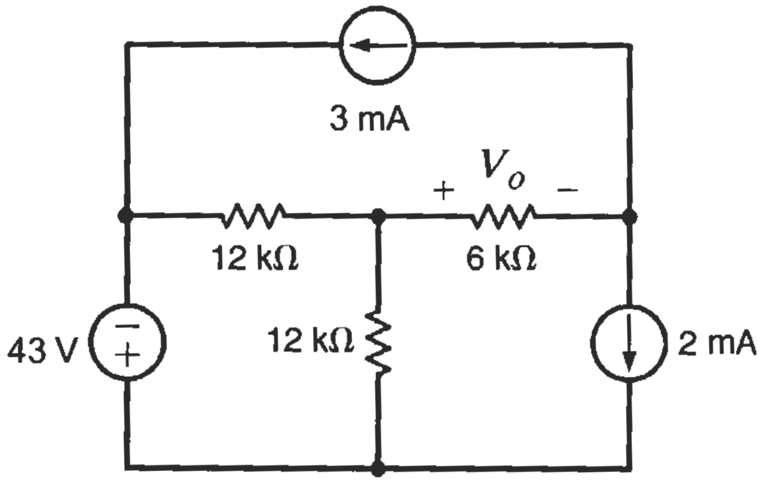
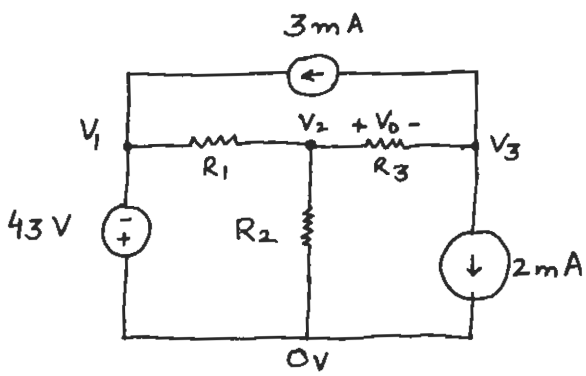


Figure P3.59

SOLUTION: 3.59



$R_1 = R_2 = 12\,k\Omega \quad , R_3 = 6\,k\Omega$

$V_1 = -43\,V$

$V_2 - V_3 = V_o \quad \text{———} \quad ①$

$$\text{KCL @ } V_2 : \quad \frac{V_2 - V_1}{R_1} + \frac{V_2 - V_3}{R_3} + \frac{V_2}{R_2} = 0$$

$$\text{KCL @ } V_3 : \quad \frac{V_3 - V_2}{R_3} + 2 \times 10^{-3} + 3 \times 10^{-3} = 0$$

$$V_2 - V_3 = 30 \quad \text{———} \quad ②$$

From equations ① and ②, we get

$$\boxed{V_o = 30.0\ V}$$

3.60 Determine V_0 in the circuit in Fig. P3.60 using loop analysis.

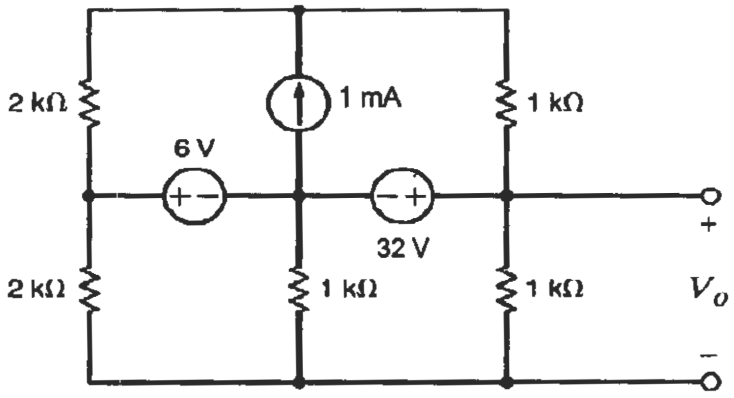
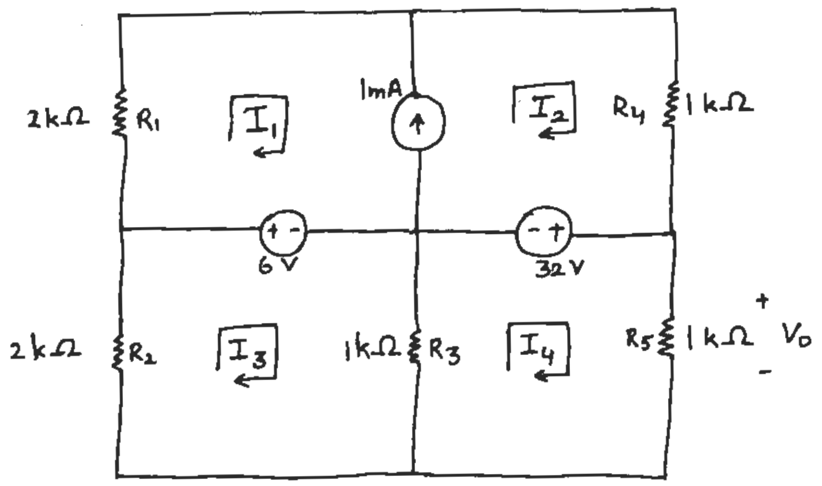


Figure P3.60

Solution: 3·60



$V_0 = I_4 R_5 \qquad\qquad I_2 - I_1 = 1\,mA$

KVL @ I_3 : $I_3 R_2 + 6 + (I_3 - I_4) R_3 = 0$

$I_3 (R_2 + R_3) - I_4 R_3 = -6$

$I_3 (3 \times 10^3) - I_4 (10^3) = -6$

$3 I_3 - I_4 = -6 \times 10^{-3}$ ______ ①

KVL @ I_4 : $(I_4 - I_3) R_3 - 32 + I_4 R_5 = 0$

$2 I_4 - I_3 = 32 \times 10^{-3}$ ______ ②

$$5 I_4 = 90 \times 10^{-3}$$

$$I_4 = 18 \text{ mA}$$

$$V_0 = I_4 R_5$$

$$V_0 = 18 \times 10^{-3} \times 10^{3}$$

$$\boxed{V_0 = 18.0 \text{ V}}$$

3.61 Find I_o in the circuit in Fig. P3.61.

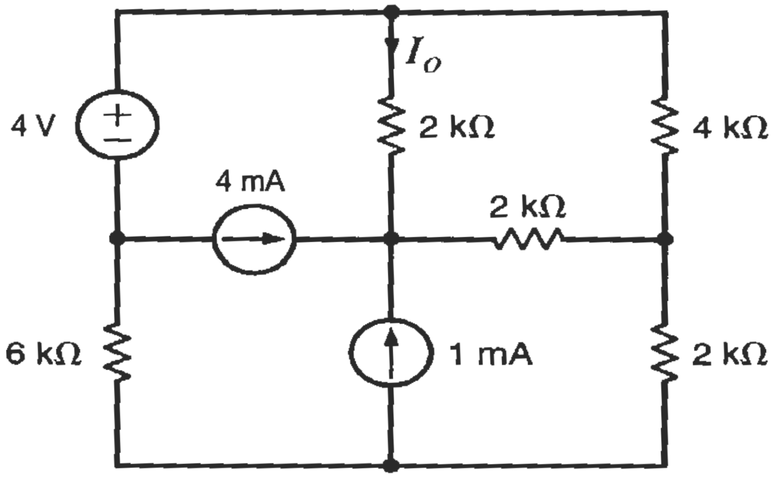
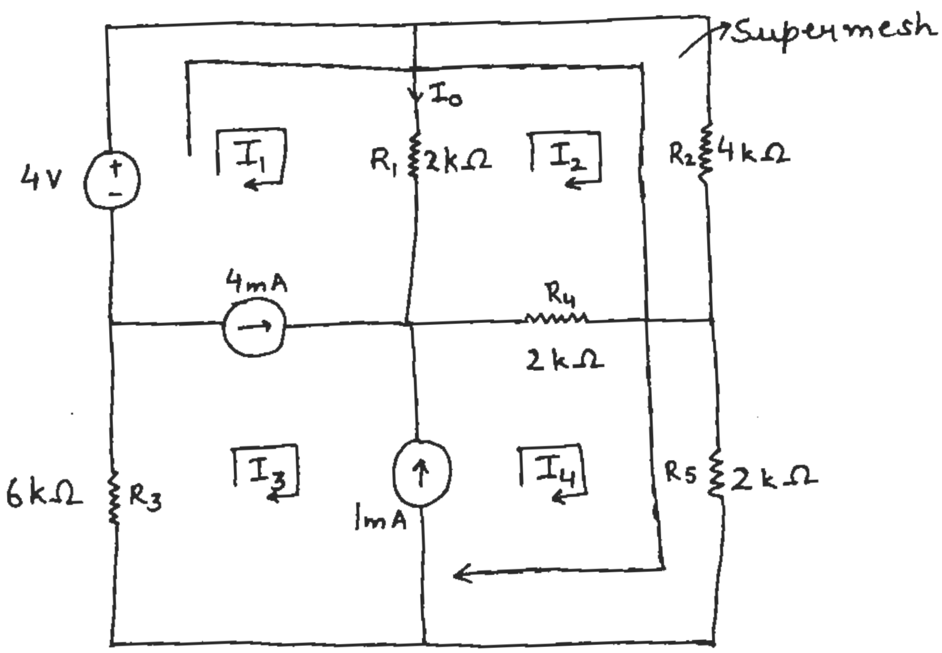


Figure P3.61

SOLUTION: 3.61



$$I_3 - I_1 = 4\times10^{-3}\,A = 4\,mA$$

$$\Rightarrow I_3 = 4mA + I_1 \quad \text{——} \quad (1)$$

$$I_4 - I_3 = 1\times10^{-3}A = 1\,mA$$

$$\Rightarrow I_4 = 1mA + I_3 = 5mA + I_1 \quad \text{——} \quad (2)$$

$$I_1 - I_2 = I_0$$

$$\Rightarrow \quad I_2 = I_1 - I_0 \quad \text{——} \quad (3)$$

KVL for I_2 : $(I_2 - I_1)R_1 + I_2 R_2 + (I_2 - I_4) R_4 = 0$

$$I_2 (R_1 + R_2 + R_4) - I_1 R_1 - I_4 R_4 = 0$$

$$I_2 (8 \times 10^3) - 2 \times 10^3 I_1 - (2 \times 10^3) I_4 = 0$$

$$\Rightarrow \quad 4 I_2 - I_1 - I_4 = 0 \quad \text{——} \quad (4)$$

KVL for supermesh : $-4 + I_2 R_2 + I_4 R_5 + I_3 R_3 = 0$

$$I_2 (4 \times 10^3) + I_4 (2 \times 10^3) + I_3 (6 \times 10^3) = 4$$

$$\Rightarrow \quad 2 I_2 + I_4 + 3 I_3 = 2 \times 10^{-3} \quad \text{——} \quad (5)$$

Substituting equations (2) and (3) in (4), we get

$$4 (I_1 - I_0) - I_1 - [(5 \times 10^{-3}) + I_1] = 0$$

$$2 I_1 - 4 I_0 = 5 \times 10^{-3} \quad \text{——} \quad (6)$$

Substituting equations (1), (2) and (3) in (5), we get

$$2(I_1 - I_0) + 5 \times 10^{-3} + I_1 + 3(4 \times 10^{-3} + I_1) = 2 \times 10^{-3}$$

$$6 I_1 - 2 I_0 = -15 \times 10^{-3} \quad \text{——} \quad (7)$$

From equations (6) and (7), we get

$$\boxed{I_0 = -3.00 \text{ mA}}$$

3.62 Use loop analysis to find I_o in the network in Fig. P3.62.

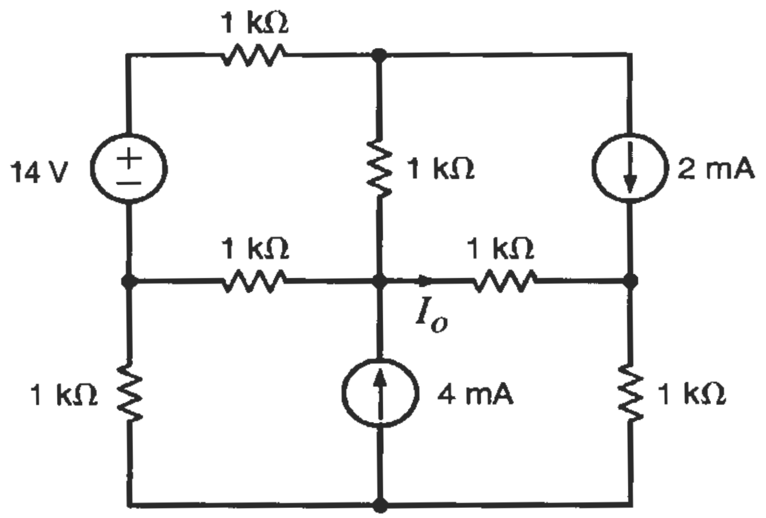
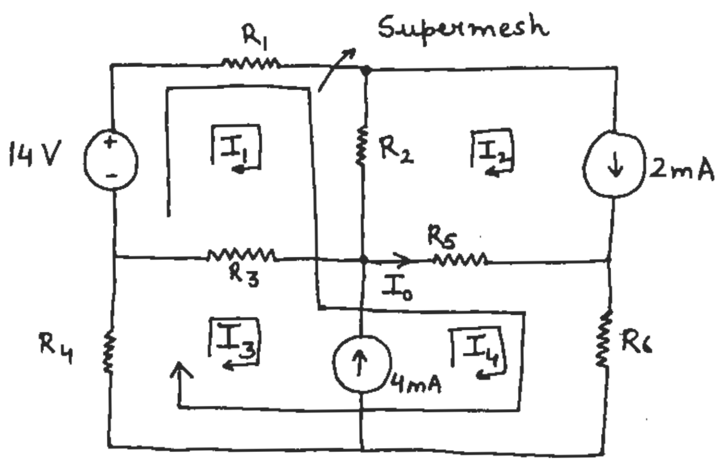


Figure P3.62

SOLUTION: 3.62



$R_1 = R_2 = R_3 = R_4 = R_5 = R_6 = 1\,k\Omega$

$I_2 = 2mA$

$I_4 - I_2 = I_o \Rightarrow I_4 = I_o + 2mA$ —— ①

$I_4 - I_3 = 4mA$

$I_3 = I_4 - 4\times10^{-3}$

$$= I_0 + 2\times10^{-3} - 4\times10^{-3}$$

$$I_3 = I_0 - 2\times10^{-3} \quad \text{—} \quad (2)$$

KVL @ I_1: $-14 + I_1R_1 + (I_1 - I_2)R_2 + (I_1 - I_3)R_3 = 0$

$$I_1(R_1 + R_2 + R_3) - I_2R_2 - I_3R_3 = 14$$

Substituting $I_2 = 2\text{mA}$, $I_3 = I_0 - 2\text{mA}$ in above equation, we get

$$3I_1 - I_0 = 14\times10^{-3} \quad \text{—} \quad (3)$$

KVL @ Supermesh: $-14 + I_1R_1 + (I_1 - I_2)R_2 + (I_4 - I_2)R_5 + I_4R_6 + I_3R_4 = 0$

$$I_1(R_1 + R_2) - I_2(R_2 + R_5) + I_3R_4 + I_4(R_5 + R_6) = 14$$

$$2I_1 - 2I_2 + I_3 + 2I_4 = 14\times10^{-3}$$

$$2I_1 - 2(2\times10^{-3}) + I_0 - 2\times10^{-3} + 2(I_0 + 2\times10^{-3}) = 14\times10^{-3}$$

$$2I_1 + 3I_0 = 16\times10^{-3} \quad \text{—} \quad (4)$$

From equations (3) and (4), we get

$$\boxed{I_0 = 1.82\text{ mA}}$$

3.63 Use loop analysis to find I_o in the network in Fig. P3.63.

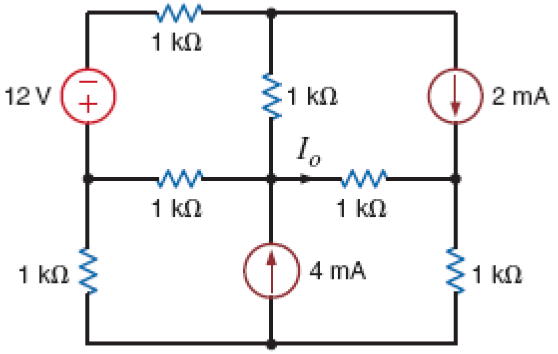
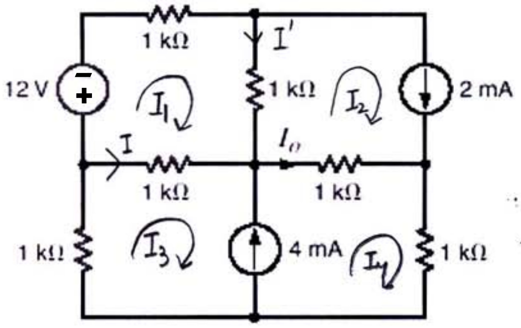


Figure P3.63

SOLUTION:



$I_2 = 2mA$

KCL: $I_3 = I + I_1$

$I = I_3 - I_1$

KCL: $I' + I_2 = I_1$

$I' = I_1 - I_2$

KCL: $I_o + 2m = I_4$

$I_o = I_4 - 2m$

KVL: $0 = 12 + 1kI_1 + 1kI' + 1k(-I)$

$1kI_1 + 1k(I_1 - I_2) - 1k(I_3 - I_1) = -12$

$3kI_1 - 1kI_2 - 1kI_3 = -12$

$$\boxed{3kI_1 - 1kI_3 = -10}$$

KVL: $1kI_3 + 1kI + 1kI_o + 1kI_4 = 0$

$1kI_3 + 1k(I_3 - I_1) + 1k(I_4 - 2m) + 1kI_4 = 0$

$$\boxed{-1kI_1 + 2kI_3 + 2kI_4 = 2}$$

KCL: $I_4 = 4m + I_3$

$$\boxed{-I_3 + I_4 = 4m}$$

KVL: $0 = 12 + 1kI_1 + 1kI' + 1kI_0 + 1kI_4 + 1kI_3$

$$1kI_1 + 1k(I_1 - I_2) + 1k(I_4 - 2m) + 1kI_4 + 1kI_3 = -12$$

$$2kI_1 - 1kI_2 + 1kI_3 + 2kI_4 = -10$$

$$\boxed{2kI_1 + 1kI_3 + 2kI_4 = -8}$$

$$3kI_1 - 1kI_3 = -10$$
$$-1kI_1 + 2kI_3 + 2kI_4 = 2$$
$$-I_3 + I_4 = 4m$$

$I_1 = -4.18mA$

$I_3 = -2.55mA$

$I_4 = 1.45mA$

$I_0 = I_4 - 2m$

$I_0 = 1.45m - 2m$

$I_0 = -0.55mA$

3.64 Use loop analysis to find V_0 in the network in the Fig. P3.64.

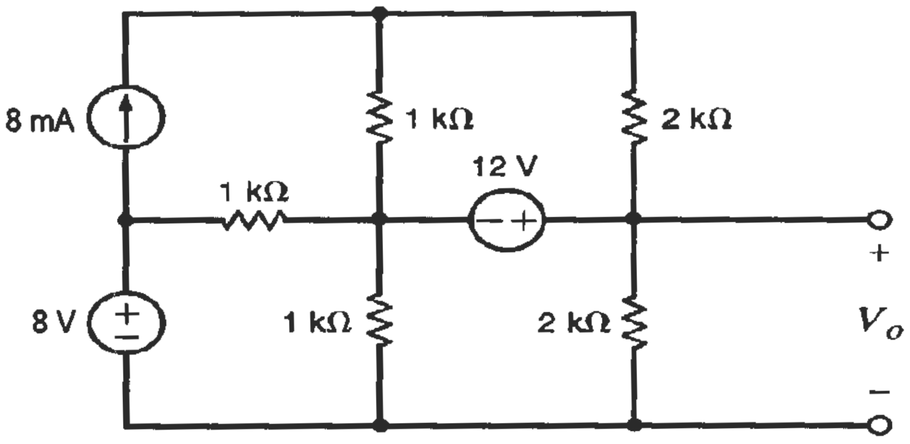
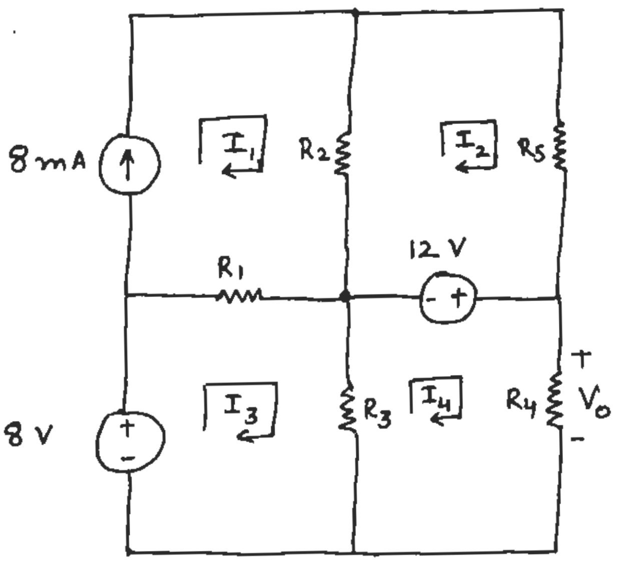


Figure P3.64

Solution: 3-64



$R_1 = R_2 = R_3 = 1\,k\Omega\,,\quad R_5 = R_4 = 2\,k\Omega$

$V_0 = I_4 R_4 \qquad \text{—} \qquad (1)$

$I_1 = 8\,mA$

KVL @ I_2: $(I_2 - I_1)R_2 + I_2 R_5 + 12 = 0$

$I_2 = -2\,mA$

KVL @ I_3 : $-8 + (I_3 - I_1)R_1 + (I_3 - I_4)R_3 = 0$

$$I_3(R_1 + R_3) - I_1 R_1 - I_4 R_3 = 8$$

$$I_3(2\times10^3) - (8\times10^{-3})(10^3) - I_4(10^3) = 8$$

$$2I_3 - I_4 = 16\times10^{-3} \quad \text{— (2)}$$

KVL @ I_4 : $(I_4 - I_3)R_3 - 12 + I_4 R_4 = 0$

$$I_4(R_3 + R_4) - I_3 R_3 = 12$$

$$(3\times10^3) I_4 - (10^3) I_3 = 12$$

$$3I_4 - I_3 = 12\times10^{-3} \quad \text{— (3)}$$

From equations (2) and (3), we get

$$I_4 = 8\,mA$$

Substituting the value of I_4 in equation (1), we get

$$V_o = (8\times10^{-3})(2\times10^3)$$

$$\boxed{V_o = 16.0\,V}$$

3.65 Using loop analysis, find V_o in the network in Fig. P3.65.

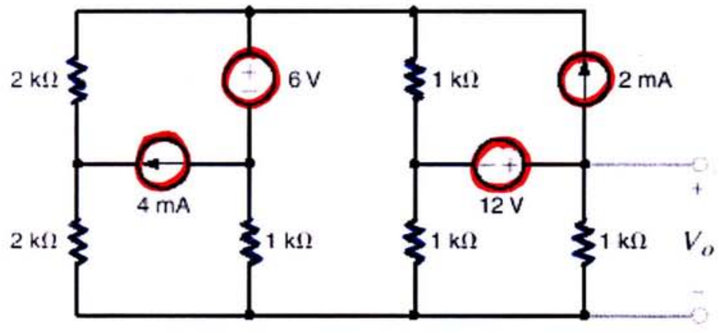
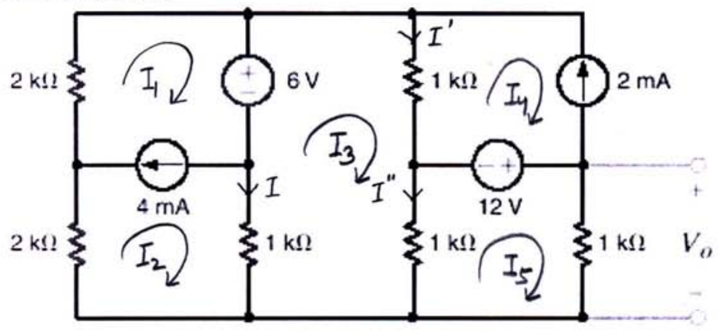


Figure P3.65

SOLUTION:



KCL: $I_3 + I = I_2$

$I = I_2 - I_3$

KCL: $I_3 = I' + I_4$

$I' = I_3 - I_4$

KCL: $I'' + I_5 = I_3$

$I'' = I_3 - I_5$

KVL: $12 = 1k\, I_5 + 1k(-I'')$

$-1k(I_3 - I_5) + 1k\, I_5 = 12$

$\boxed{-1k I_3 + 2k I_5 = 12}$

KVL: $6 = 1k\, I' + 1k\, I'' + 1k(-I)$

$1k(I_3 - I_4) + 1k(I_3 - I_5) - 1k(I_2 - I_3) = 6$

$$\boxed{-1kI_2 + 3kI_3 - 1kI_4 - 1kI_5 = 6}$$

KVL: $2kI_1 + 1kI' + 1kI_5 + 2kI_2 = 12$

$$2kI_1 + 1k(I_3 - I_4) + 1kI_5 + 2kI_2 = 12$$

$$\boxed{2kI_1 + 2kI_2 + 1kI_3 - 1kI_4 + 1kI_5 = 12}$$

KCL: $I_2 + 4m = I_1$

$$\boxed{-I_1 + I_2 = -4m}$$

$I_4 = -2mA$

$$-1kI_2 + 3kI_3 - 1k(-2m) - 1kI_5 = 6$$

$$\boxed{-1kI_2 + 3kI_3 - 1kI_5 = 4}$$

$$2kI_1 + 2kI_2 + 1kI_3 - 1k(-2m) + 1kI_5 = 12$$

$$\boxed{2kI_1 + 2kI_2 + 1kI_3 + 1kI_5 = 10}$$

$$0I_1 + 0I_2 - 1kI_3 - 1k(-2m) + 1kI_5 = 12$$

$$-I_1 + I_2 + 0I_3 + 0I_5 = -4m$$

$$0I_1 - 1kI_2 + 3kI_3 - 1kI_5 = 4$$

$$2kI_1 + 2kI_2 + 1kI_3 + 1kI_5 = 10$$

$I_1 = 1.83mA$

$I_2 = -2.17mA$

$I_3 = 3.13mA$

$I_5 = 7.57mA$

$V_o = 1k(I_5) = 1k(7.57m)$

$V_o = 7.57V$

3.66 Using loop analysis, find I_o in the circuit in Fig. P3.66.

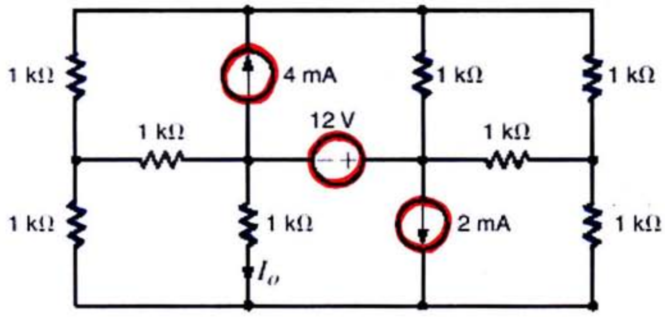
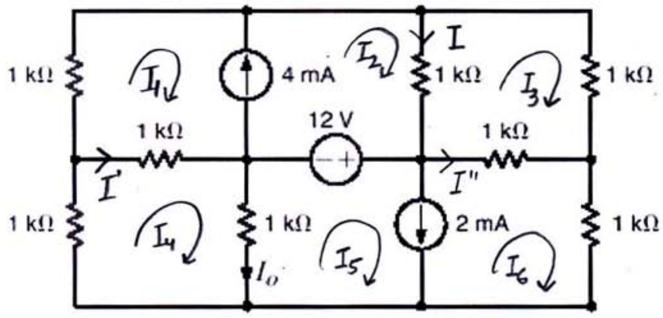


Figure P3.66

SOLUTION:



KCL: $I_2 = I + I_3$

$I = I_2 - I_3$

KCL: $I_3 + I'' = I_6$

$I'' = I_6 - I_3$

KCL: $I_4 = I_1 + I'$

$I' = I_4 - I_1$

KCL: $I_0 + I_5 = I_4$

$I_0 = I_4 - I_5$

KVL: $12 = 1kI'' + 1kI_6 + 1k(-I_0)$

$1k(I_6 - I_3) + 1kI_6 - 1k(I_4 - I_5) = 12$

$$\boxed{-1kI_3 - 1kI_4 + 1kI_5 + 2kI_6 = 12}$$

KVL: $1kI' + 1kI_0 + 1kI_4 = 0$

$1k(I_4 - I_1) + 1k(I_4 - I_5) + 1kI_4 = 0$

$$\boxed{-1kI_1 + 3kI_4 - 1kI_5 = 0}$$

KCL: $I_6 + 2m = I_5$

$$\boxed{-I_5 + I_6 = -2m}$$

KCL: $I_1 + 4m = I_2$

$$\boxed{I_1 - I_2 = -4m}$$

KVL: $1kI_1 + 1kI_3 + 1k(-I'') + 12 + 1k(-I') = 0$

$1kI_1 + 1kI_3 - 1k(I_6 - I_3) - 1k(I_4 - I_1) = -12$

$$\boxed{2kI_1 + 2kI_3 - 1kI_4 - 1kI_6 = -12}$$

KVL: $1kI_3 + 1k(-I'') + 1k(-I) = 0$

$1kI_3 - 1k(I_6 - I_3) - 1k(I_2 - I_3) = 0$

$$\boxed{-1kI_2 + 3kI_3 - 1kI_6 = 0}$$

$0I_1 + 0I_2 - 1kI_4 + 1kI_5 + 2kI_6 = 12$

$-1kI_1 + 0I_2 + 0I_3 + 3kI_4 - 1kI_5 + 0I_6 = 0$

$0I_1 + 0I_2 + 0I_3 + 0I_4 - I_5 + I_6 = -2m$

$I_1 - I_2 + 0I_3 + 0I_4 + 0I_5 + 0I_6 = -4m$

$2kI_1 + 0I_2 + 2kI_3 - 1kI_4 + 0I_5 - 1kI_6 = -12$

$0I_1 - 1kI_2 + 3kI_3 + 0I_4 + 0I_5 - 1kI_6 = 0$

$$I_1 = -4.93mA$$

$$I_2 = -0.933mA$$

$$I_3 = 0.933mA$$

$$I_4 = 0.267mA$$

$$I_5 = 5.73mA$$

$$I_6 = 3.73mA$$

$$I_0 = I_4 - I_5 = 0.267m - 5.73m$$

$$I_0 = -5.46mA$$

3.67 Use MATLAB to find the mesh currents in the network in Fig. P3.6.

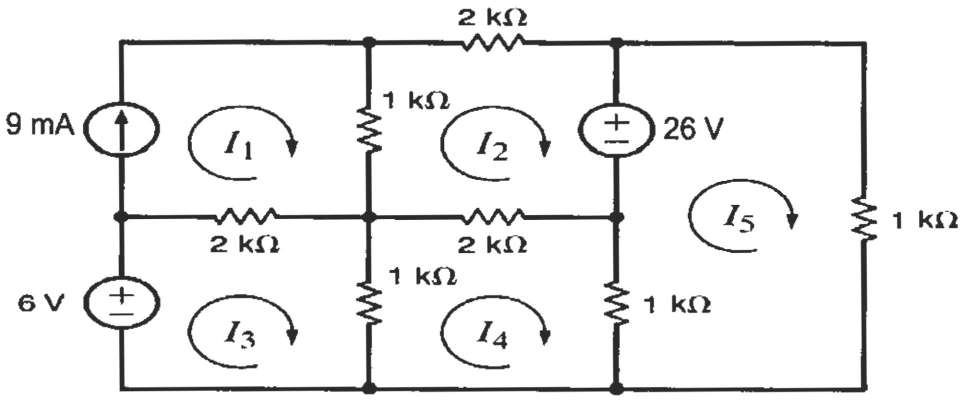
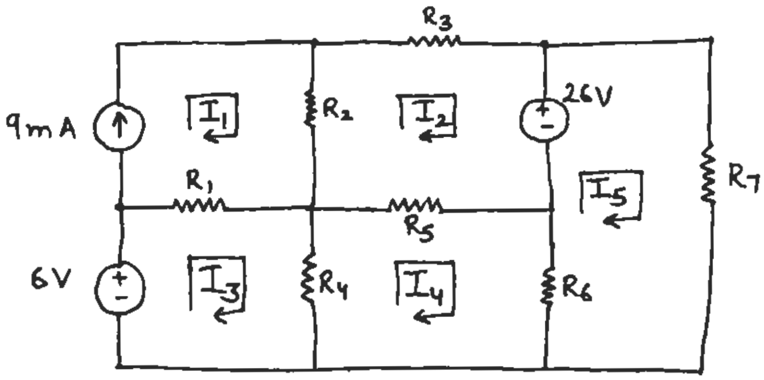


Figure P3.67

SOLUTION: 3.67



$R_1 = R_3 = R_5 = 2k\Omega, \; R_2 = R_4 = R_6 = R_7 = 1\,k\Omega$

$I_1 = 9 \times 10^{-3}\,A$

KVL @ I_2: $(I_2 - I_1)R_2 + I_2 R_3 + 26 + (I_2 - I_4)R_5 = 0$

$$-I_1(R_2) + I_2(R_2 + R_3 + R_5) - I_4 R_5 = -26$$

$$-I_1(10^3) + I_2(5\times10^3) - I_4(2\times10^3) = -26$$

$$-I_1 + 5I_2 - 2I_4 = -26\times10^{-3}$$

KVL @ I_3: $-6 + (I_3 - I_1)R_1 + (I_3 - I_4)R_4 = 0$

$$-I_1 R_1 + I_3(R_1 + R_4) - I_4(R_4) = 6$$

$$-I_1(2\times10^3) + I_3(3\times10^3) - I_4(10^3) = 6$$

$$-2I_1 + 3I_3 - I_4 = 6\times10^{-3}$$

KVL @ I_4: $(I_4 - I_3)R_4 + (I_4 - I_2)R_5 + (I_4 - I_5)R_6 = 0$

$$-I_2 R_5 - I_3 R_4 + I_4(R_4 + R_5 + R_6) - I_5 R_6 = 0$$

$$-I_2(2\times10^3) - I_3(10^3) + I_4(4\times10^3) - I_5(10^3) = 0$$

$$-2I_2 - I_3 + 4I_4 - I_5 = 0$$

KVL @ I_5: $-26 + I_5 R_7 + (I_5 - I_4)R_6 = 0$

$$-I_4 R_6 + I_5(R_6 + R_7) = 26$$

$$-I_4(10^3) + I_5(2\times10^3) = 26$$

$$-I_4 + 2I_5 = 26\times10^{-3}$$

In matrix form

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ -1 & 5 & 0 & -2 & 0 \\ -2 & 0 & 3 & -1 & 0 \\ 0 & -2 & -1 & 4 & -1 \\ 0 & 0 & 0 & -1 & 2 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \end{bmatrix} = \begin{bmatrix} 0.009 \\ -0.026 \\ 0.006 \\ 0 \\ 0.026 \end{bmatrix}$$

3.68 Use loop analysis to find V_o in the network in Fig. P3.68.

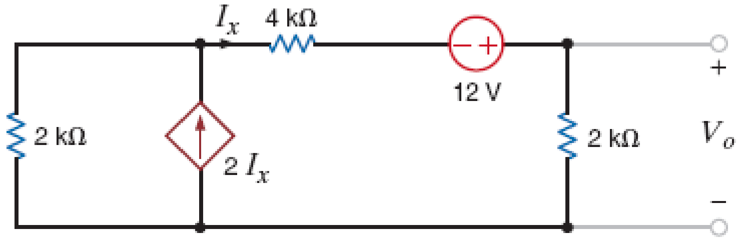
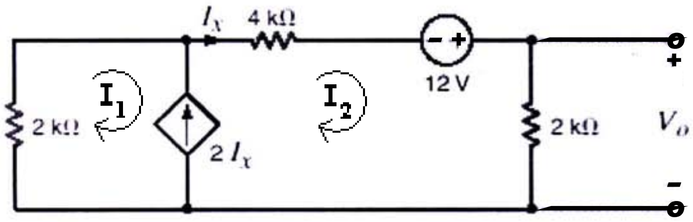


Figure P3.68

SOLUTION:



KCL: $I_1 + 2I_x = I_x$

$I_1 = -I_x$ and $I_2 = I_x$

KVL: $12 = 2kI_1 + 4kI_2 + 2kI_2$

$2kI_1 + 6kI_2 = 12$

$2k(-I_x) + 6k(I_x) = 12$

$4kI_x = 12$

$I_x = 3mA$

$V_0 = 2kI_x = 2k(3m)$

$V_0 = 6V$

3.69 Find V_o in the circuit in Fig. P3.69 using nodal analysis.

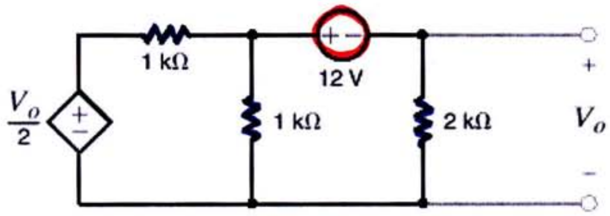
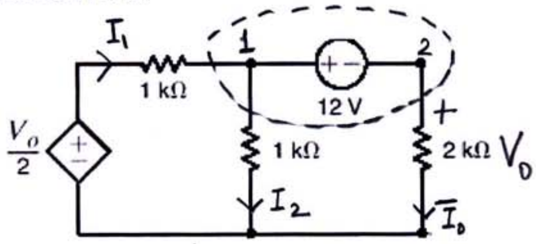


Figure P3.69

SOLUTION:



KCL at supernode:

$$I_1 = I_2 + I_0$$

$$\frac{\frac{V_0}{2} - V_1}{1k} = \frac{V_1}{1k} + \frac{V_2}{2k}$$

$$V_0 - 2V_1 = 2V_1 + V_2$$

$$V_2 = V_0$$

$$V_1 = 0V$$

$$V_1 - V_2 = 12$$

$$V_2 = -12V$$

$$V_0 = -12V$$

3.70 Use nodal analysis to find V_o in Fig. P3.70.

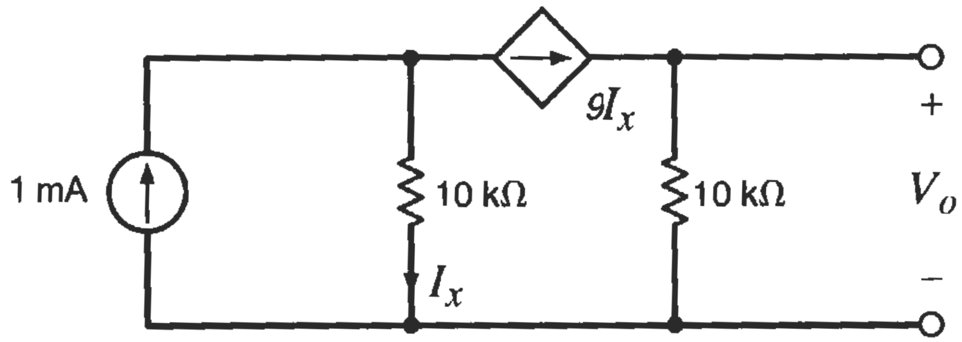
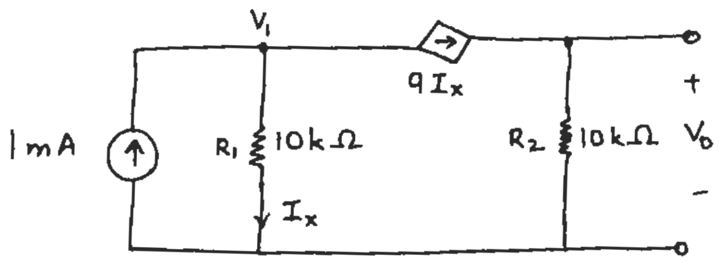


Figure P3.70

SOLUTION: 3.70



$R_1 = R_2 = 10\,k\Omega$

$$I_x = \frac{V_1}{R_1} \Rightarrow I_x = \frac{V_1}{10 \times 10^3} = \frac{V_1}{10} \times 10^{-3}$$

KCL @ V_1 : $$-1 \times 10^{-3} + \frac{V_1}{R_1} + 9 I_x = 0$$

$$V_1 = 1\ V$$

KCL @ V_o : $$-9 I_x + \frac{V_o}{R_2} = 0$$

$$V_o = 9 V_1$$

$$\boxed{V_o = 9\ V}$$

3.71 Use nodal analysis to find V_o in the network in Fig. P3.71.

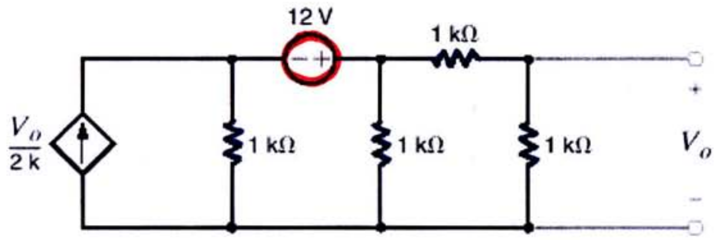
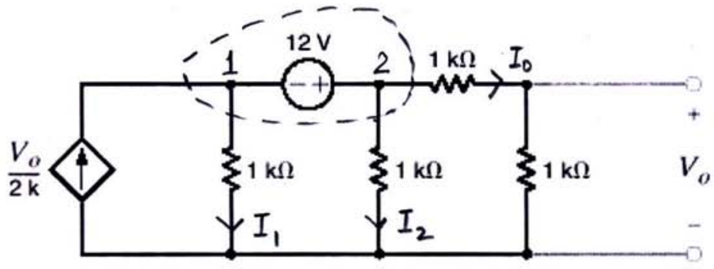


Figure P3.71

SOLUTION:



KCL at supernode:

$$\frac{V_0}{2k} = I_1 + I_2 + I_0$$

$$\frac{V_1}{1k} + \frac{V_2}{1k} + \frac{V_2}{1k+1k} = \frac{V_0}{2k}$$

$$2V_1 + 2V_2 + V_2 = V_0$$

$$\boxed{2V_1 + 3V_2 = V_0}$$

$$\boxed{-V_1 + V_2 = 12}$$

$$V_0 = I_0(1k)$$

$$I_0 = \frac{V_2}{1k+1k} = \frac{V_2}{2k}$$

$$\boxed{V_0 = \frac{V_2}{2}}$$

$$2V_1 + 3V_2 = \frac{V_2}{2}$$

$$4V_1 + 6V_2 = V_2$$

$$\boxed{4V_1 + 5V_2 = 0}$$

$$-V_1 + V_2 = 12$$
$$4V_1 + 5V_2 = 0$$

$$V_1 = -6.67V$$
$$V_2 = 5.33V$$

$$V_0 = \frac{V_2}{2} = \frac{5.33}{2}$$

$$V_0 = 2.67V$$

3.72 Find the power supplied by the 4-A current source in the network in Fig. P3.72 using nodal analysis.

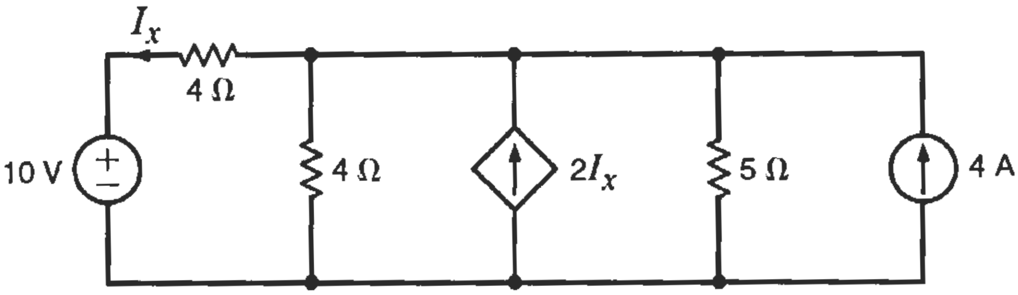
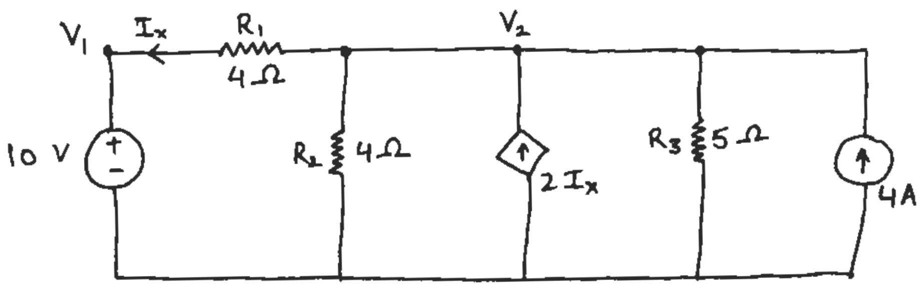


Figure P3.72

SOLUTION: 3.72



$R_1 = R_2 = 4\,\Omega, \quad R_3 = 5\,\Omega$

$V_1 = 10\text{ V}; \quad I_x = \dfrac{V_2 - V_1}{R_1} = \dfrac{V_2 - V_1}{4} = \dfrac{V_2 - 10}{4}\text{ A}$

KCL @ V_2: $\dfrac{V_2 - V_1}{R_1} + \dfrac{V_2}{R_2} - 2I_x + \dfrac{V_2}{R_3} - 4 = 0$

$$\frac{V_2 - 10}{4} + \frac{V_2}{4} - 2\left(\frac{V_2 - 10}{4}\right) + \frac{V_2}{5} - 4 = 0$$

$$V_2 = 7.5\text{ V}$$

Power supplied by 4-A source,

$$P_{4A} = 4 \times 7.5$$

$$\boxed{P_{4A} = 30.0\text{ W}}$$

3.73 Find I_o in the network in Fig. P3.73.

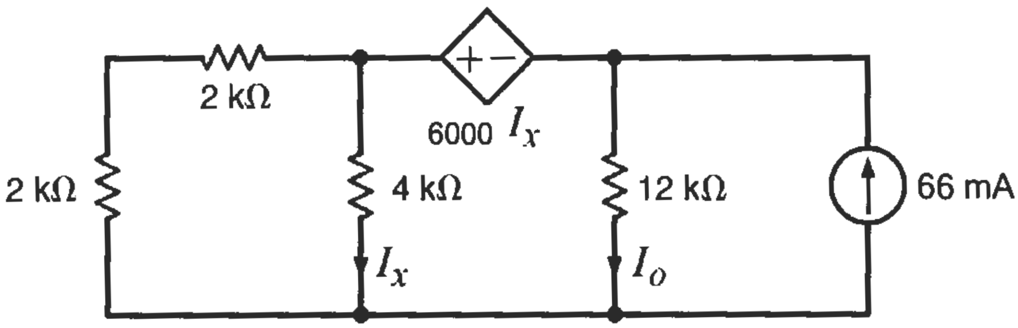
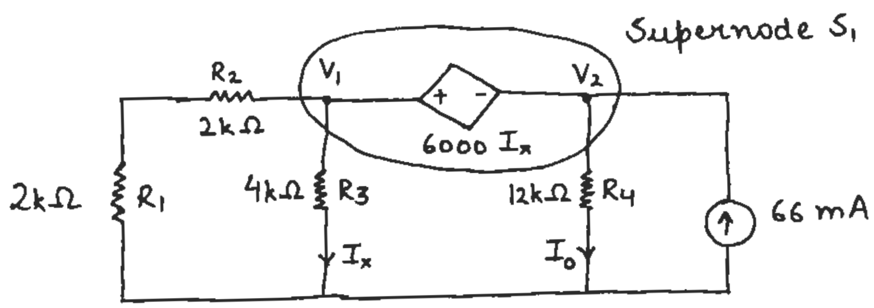


Figure P3.73

SOLUTION: 3.73



$R_1 = R_2 = 2\,k\Omega$, $R_3 = 4\,k\Omega$, $R_4 = 12\,k\Omega$

$V_1 - V_2 = 6000\,I_x$

Using $I_x = \frac{V_1}{R_3}$,

$V_1 - V_2 = \frac{3}{2}V_1 \quad \Rightarrow \quad V_1 = -2V_2 \quad \text{—— (1)}$

KCL @ S_1 : $\frac{V_1}{R_1+R_2} + \frac{V_1}{R_3} + \frac{V_2}{R_4} - 66 \times 10^{-3} = 0$

$6V_1 + V_2 = 792 \quad \text{—— (2)}$

From equations (1) and (2) we get,

$-11V_2 = 792$

$V_2 = -72.0V$

$$I_O = \frac{V_2}{R_4}$$

$$= \frac{-72}{12 \times 10^3}$$

$$\boxed{I_O = -6mA}$$

3.74 Find V_o in the circuit in Fig. P3.74 using nodal analysis.

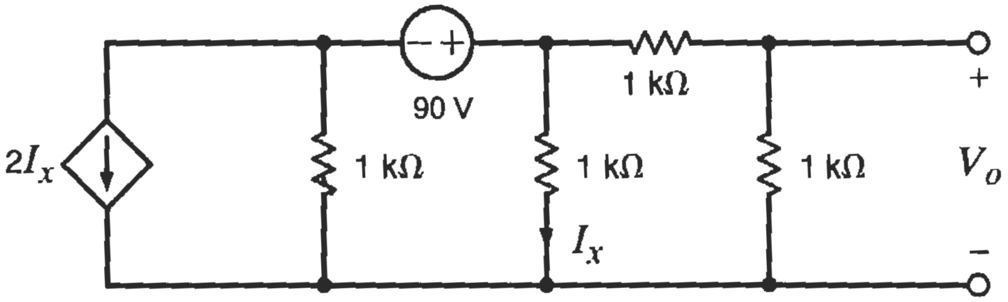
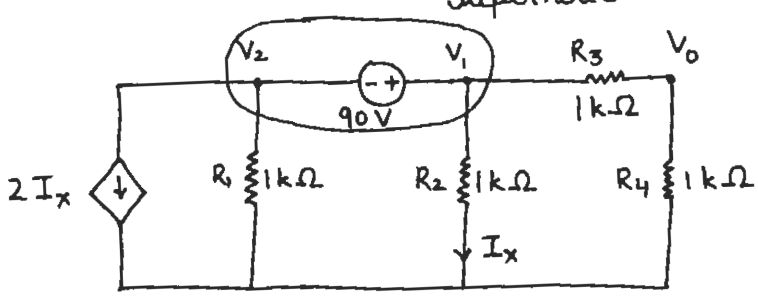


Figure P3.74

SOLUTION: 3.74



$R_1 = R_2 = R_3 = R_4 = 1\,k\Omega$

$V_1 - V_2 = 90\ V$ —— ①

$I_x = \dfrac{V_1}{R_2} = \dfrac{V_1}{10^3}$

KCL @ Supernode: $2I_x + \dfrac{V_2}{R_1} + \dfrac{V_1}{R_2} + \dfrac{V_1 - V_o}{R_3} = 0$

$4V_1 + V_2 - V_o = 0$ —— ②

KCL @ V_o : $\dfrac{V_o}{R_4} + \dfrac{V_o - V_1}{R_3} = 0$

$V_o = \dfrac{V_1}{2}$ —— ③

Substituting equation ③ in ②, we get

$4V_1 + V_2 - \dfrac{V_1}{2} = 0$

$$7V_1 + 2V_2 = 0 \quad \text{—} \quad (4)$$

From equations (1) and (4), we get

$$V_1 = 20\text{ V}$$

$$V_0 = \frac{V_1}{2}$$

$$\boxed{V_0 = 10\text{ V}}$$

3.75 Find V_o in the network in Fig. P3.75 using nodal analysis.

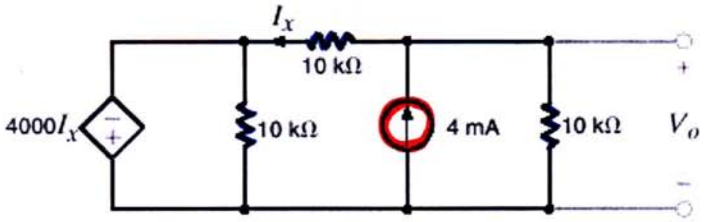
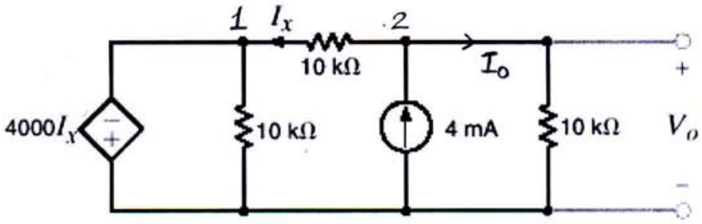


Figure P3.75

SOLUTION:



$$V_1 = -4000 I_x$$

$$I_x = \frac{V_2 - V_1}{10k}$$

KCL at 2: $4m = I_x + I_o$

$$\frac{V_2 - V_1}{10k} + \frac{V_2}{10k} = 4m$$

$$V_2 - V_1 + V_2 = 40$$

$$\boxed{-V_1 + 2V_2 = 40}$$

$$V_1 = -4000\left(\frac{V_2 - V_1}{10k}\right)$$

$$V_1 = -2/5\, V_2 + 2/5\, V_1$$

$$5V_1 = -2V_2 + 2V_1$$

$$\boxed{-3V_1 - 2V_2 = 0}$$

$$-V_1 + 2V_2 = 40$$

$$-3V_1 - 2V_2 = 0$$

$$V_1 = -10V$$

$$V_2 = 15V$$

$$V_0 = V_2 = 15V$$

$$V_0 = 15V$$

3.76 Use both nodal analysis and mesh analysis to find V_o in the circuit in Fig. P3.76.

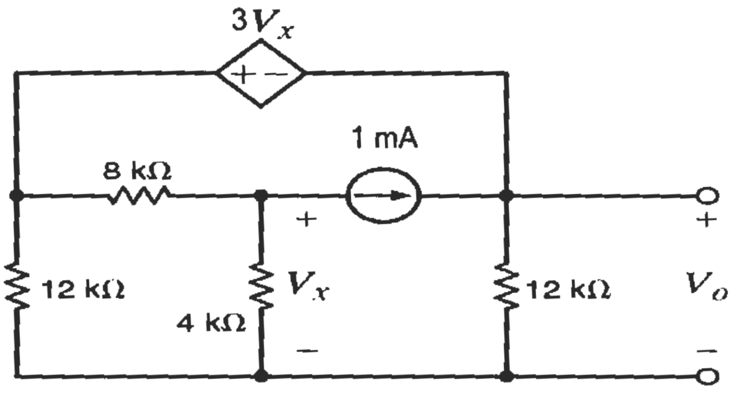
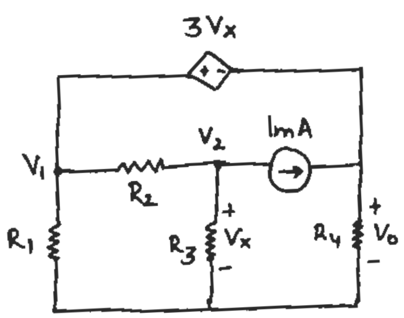


Figure P3.76

SOLUTION: 3.76 (a)



$R_1 = R_4 = 12\,k\Omega,\ R_2 = 8\,k\Omega,\ R_3 = 4\,k\Omega,\ V_x = V_2$

$$V_1 - V_0 = 3V_x$$

$$\Rightarrow V_1 - V_0 = 3V_2 \quad \text{———} \quad (1)$$

$$\text{KCL @ } V_2 :\ \frac{V_2 - V_1}{R_2} + \frac{V_2}{R_3} + 1 \times 10^{-3} = 0$$

$$3V_2 - V_1 = -8$$

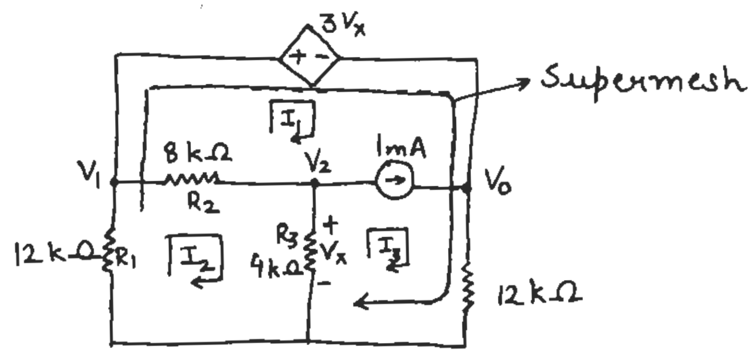
$$V_2 = \frac{-8 + V_1}{3} \quad \text{———} \quad (2)$$

Substituting equation (2) in (1), we get

$$V_1 - V_0 = \frac{3(V_1 - 8)}{3}$$

$$\boxed{V_0 = 8.00\ V}$$

3.76(b)



$R_1 = R_4 = 12\,k\Omega,\; R_2 = 8\,k\Omega,\; R_3 = 4\,k\Omega$

$I_3 - I_1 = 10^{-3}A$ — (1)

$V_x = (I_2 - I_3)R_3$

$V_0 = I_3 R_4$

KVL @ Supermesh : $3V_x + I_3R_4 + I_2R_1 = 0$

$3I_2R_3 - 3I_3R_3 + I_3R_4 + I_2R_1 = 0$

$I_2 = 0A$ — (2)

KVL @ I_2 : $I_2R_1 + (I_2 - I_1)R_2 + (I_2 - I_3)R_3 = 0$

$2I_1 + I_3 = 0$

$I_1 = -\frac{I_3}{2}$ — (3)

Substituting equation (3) in (2), we get

$I_3 = \frac{2}{3} \times 10^{-3} A$

$V_0 = I_3 R_4$

$\boxed{V_0 = 8.00\ V}$

3.77 Find V_x in the circuit in Fig. P3.77.

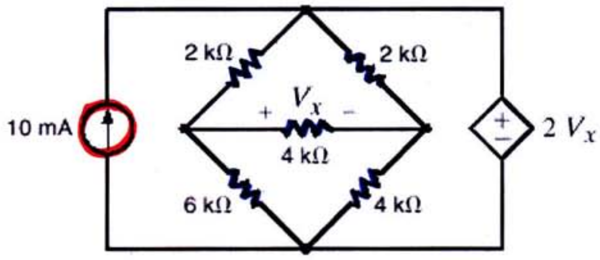
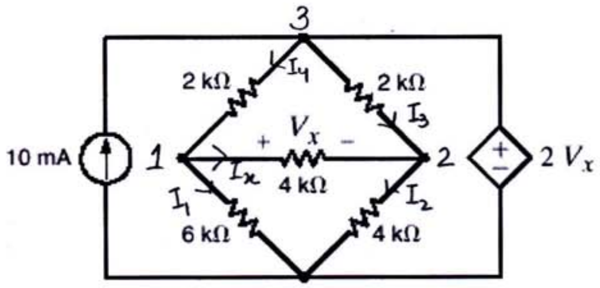


Figure P3.77

SOLUTION:



KCL at 1: $I_4 = I_x + I_1$

$$\frac{V_3 - V_1}{2k} = \frac{V_1 - V_2}{4k} + \frac{V_1}{6k}$$

$$6V_3 - 6V_1 = 3V_1 - 3V_2 + 2V_1$$

$$\boxed{11V_1 - 3V_2 - 6V_3 = 0}$$

KCL at 2: $I_x + I_3 = I_2$

$$\frac{V_1 - V_2}{4k} + \frac{V_3 - V_2}{2k} = \frac{V_2}{4k}$$

$$V_1 - V_2 + 2V_3 - 2V_2 = V_2$$

$$\boxed{V_1 - 4V_2 + 2V_3 = 0}$$

$$V_3 = 2V_x$$

$$V_x = V_1 - V_2$$

$$V_3 = 2(V_1 - V_2)$$

$$\boxed{2V_1 - 2V_2 - V_3 = 0}$$

$$11V_1 - 3V_2 - 6V_3 = 0$$
$$V_1 - 4V_2 + 2V_3 = 0$$
$$2V_1 - 2V_2 - V_3 = 0$$

$$V_1 = 0V$$
$$V_2 = 0V$$
$$V_3 = 0V$$

$$V_x = V_1 - V_2$$
$$V_x = 0V$$

3.78 Using mesh analysis, find V_o in the circuit in Fig. P3.78.

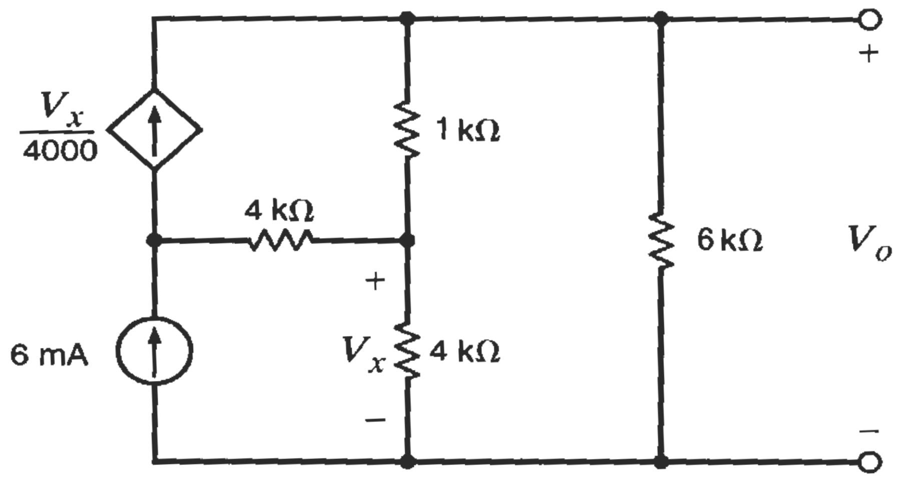
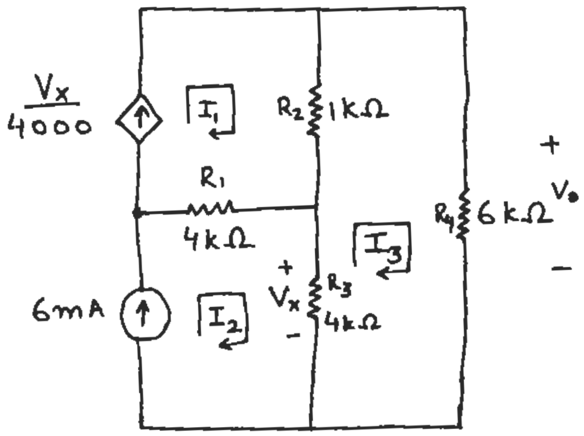


Figure P3.78

SOLUTION: 3.78



$R_1 = R_3 = 4\,k\Omega$, $R_2 = 1\,k\Omega$, $R_4 = 6\,k\Omega$

$I_2 = 6 \times 10^{-3}$ A ——— ①

$V_x = (I_2 - I_3) R_3$ ——— ②

$I_1 = \dfrac{V_x}{4000}$ ——— ③

$V_o = I_3 R_4$

KVL @ I_3: $(I_3 - I_1)R_2 + I_3 R_4 + (I_3 - I_2)R_3 = 0$

$$11 I_3 - I_1 = 24 \times 10^{-3} \quad \text{——} \quad (4)$$

Substituting equations (1) and (2) in (3), we get

$$I_1 = 6 \times 10^{-3} - I_3 \quad \text{——} \quad (5)$$

Substituting equation (5) in (4), we get

$$I_3 = \frac{30}{12} \times 10^{-3}\ A$$

$$V_o = I_3 R_4$$

$$= \frac{30}{12} \times 10^{-3} \times 6 \times 10^{3}$$

$$\boxed{V_o = 15.0\,V}$$

3.79 Find I_o in the circuit in Fig. P3.79.

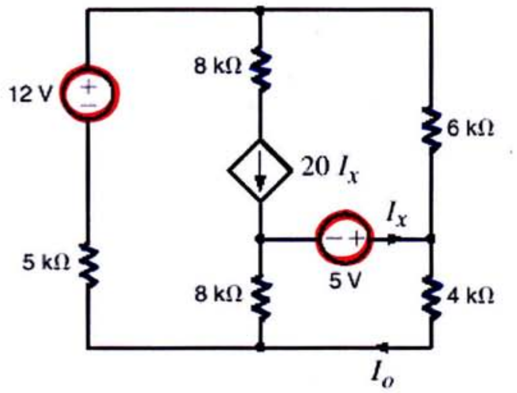
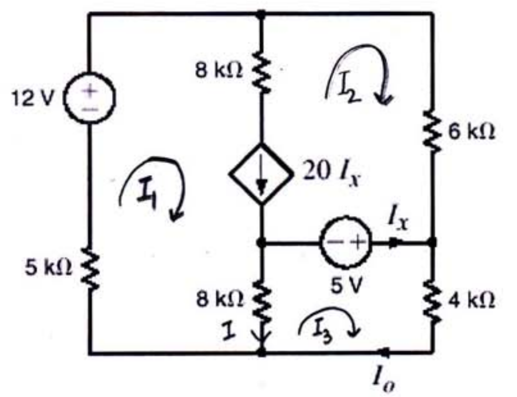


Figure P3.79

SOLUTION:



KVL: $12 = 5kI_1 + 6kI_2 + 4kI_3$

$$\boxed{5kI_1 + 6kI_2 + 4kI_3 = 12}$$

KCL: $I + I_3 = I_1$

$I = I_1 - I_3$

KVL: $5 = 4kI_3 + 8k(-I)$

$4kI_3 - 8k(I_1 - I_3) = 5$

$$\boxed{-8kI_1 + 12kI_3 = 5}$$

KCL: $I_1 = 20I_x + I_2$

$I_1 - I_2 - 20(I_3 - I_2) = 0$

$$\boxed{I_1 + 19I_2 - 20I_3 = 0}$$

$$5kI_1 + 6kI_2 + 4kI_3 = 12$$
$$-8kI_1 + 0I_2 + 12kI_3 = 5$$
$$I_1 + 19I_2 - 20I_3 = 0$$

$$I_1 = 0.66\text{mA}$$
$$I_2 = 0.871\text{mA}$$
$$I_3 = 0.861\text{mA}$$

$$I_0 = I_3$$
$$I_0 = 0.861\text{mA}$$

3.80 Write mesh equations for the circuit in Fig. P3.80 using the assigned currents.

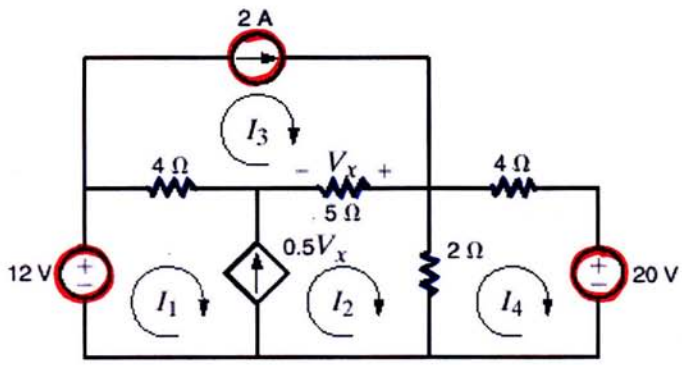
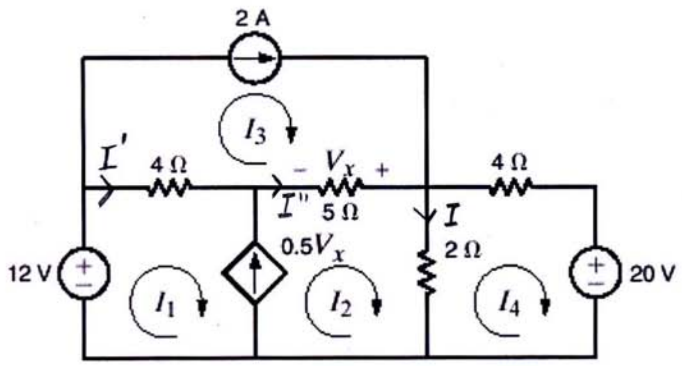


Figure P3.80

SOLUTION:



KCL: $I_1 = I' + I_3$

$I' = I_1 - I_3$

KCL: $I + I_4 = I_2$

$I = I_2 - I_4$

KCL: $I'' + I_3 = I + I_4$

$I'' = -I_3 + I_4 + I_2 - I_4$

$I'' = I_2 - I_3$

KCL: $I_2 = 0.5V_x + I_1$

$-I_1 + I_2 - 0.5V_x = 0$

$V_x = -I''(5) = -5(I_2 - I_3)$

$$V_x = -5I_2 + 5I_3$$

$$-I_1 + I_2 - 0.5(-5I_2 + 5I_3) = 0$$

$$\boxed{-I_1 + 3.5I_2 - 2.5I_3 = 0}$$

$$I_3 = 2A$$

$$\text{KVL: } 4I_4 + 20 + 2(-I) = 0$$

$$4I_4 - 2(I_2 - I_4) = -20$$

$$\boxed{-2I_2 + 16I_4 = -20}$$

$$\text{KVL: } 12 = 4I' + 5I'' + 4I_4 + 20$$

$$4(I_1 - I_3) + 5(I_2 - I_3) + 4I_4 = -8$$

$$4I_1 + 5I_2 - 9I_3 + 4I_4 = -8$$

$$\boxed{4I_1 + 5I_2 + 4I_4 = 10}$$

$$-I_1 + 3.5I_2 - 2.5I_3 = 0$$

$$-2I_2 + 6I_4 = -20$$

$$4I_1 + 5I_2 + 4I_4 = 10$$

$$I_3 = 2A$$

$$-I_1 + 3.5I_2 = 5$$

$$-2I_2 + 6I_4 = -20$$

$$4I_1 + 5I_2 + 4I_4 = 10$$

$$I_1 = 2.46A$$

$$I_2 = 2.13A$$

$$I_4 = -2.62A$$

3.81 Find V_o in the network in Fig. P3.81.

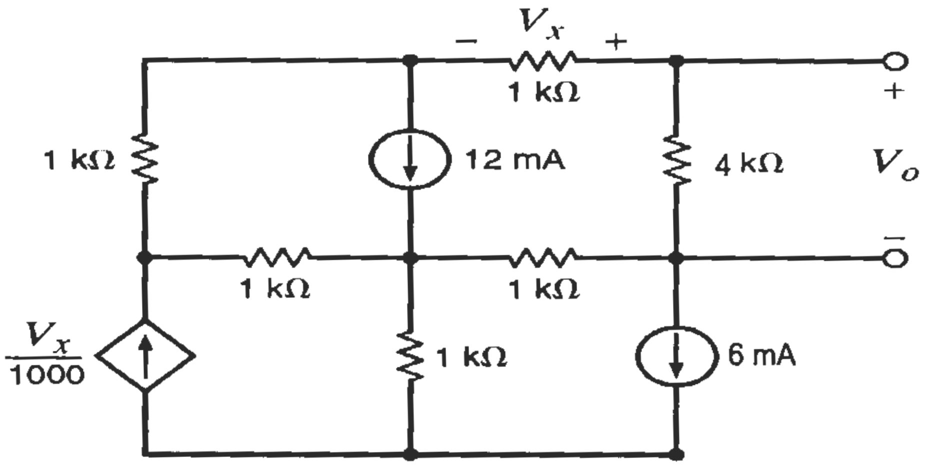
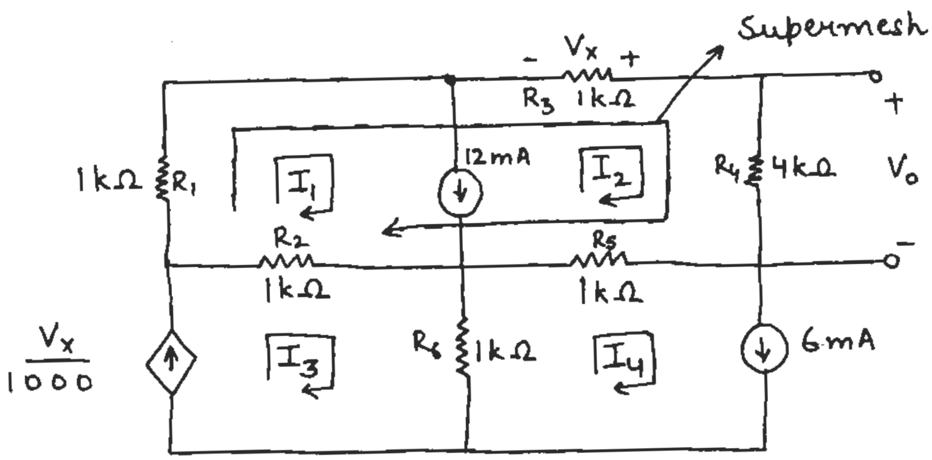


Figure P3.81

SOLUTION: 3.81



$$R_1 = R_2 = R_3 = R_5 = R_6 = 1\,k\Omega \,,\; R_4 = 4\,k\Omega$$

$$I_1 - I_2 = 12\,mA \qquad \text{(1)}$$

$$I_4 = 6\,mA$$

$$V_x = -I_2 R_3$$

$$I_3 = \frac{V_x}{1000}$$

$$V_0 = I_2 R_4$$

KVL @ supermesh: $I_1 R_1 + I_2 R_3 + I_2 R_4 + (I_2 - I_4) R_5 + (I_1 - I_3) R_2 = 0$

$$I_1 (R_1 + R_2) + I_2 (R_3 + R_4 + R_5) - I_3 R_2 - I_4 R_5 = 0$$

$$2\times10^3 I_1 + 6\times10^3 I_2 - 10^3 I_3 - 10^3 I_4 = 0$$

$$2I_1 + 6I_2 - I_3 - I_4 = 0$$

Substituting $I_3 = \frac{V_x}{1000}$ and $V_x = -I_2 R_3$

$$2I_1 + 7I_2 = 6\times10^{-3} \quad — \quad ②$$

From equations ① and ②, we get

$$I_2 = -2mA$$

$$V_0 = I_2 R_4$$

$$V_0 = -2\times10^{-3} \times 4\times10^3$$

$$\boxed{V_0 = -8.00\text{ V}}$$

3.82 Using nodal analysis, find V_o in the circuit in Fig. P3.82.

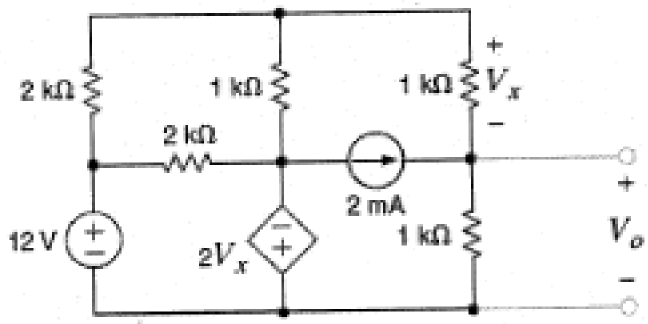
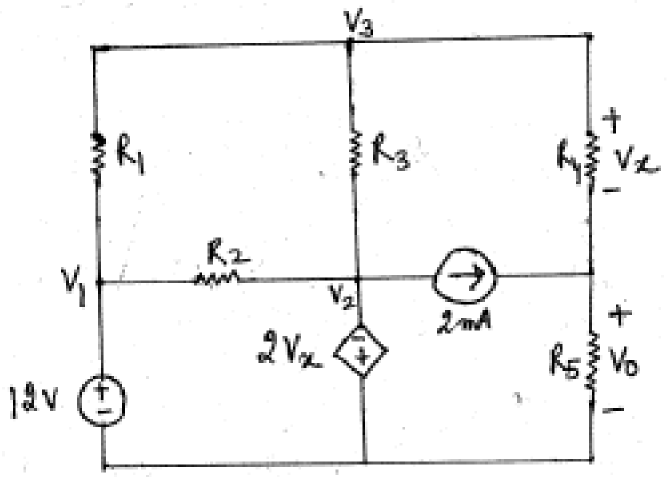


Figure P3.82

Solution : 3.82



$R_1 = R_2 = 2k\Omega$

$R_3 = R_4 = R_5 = 1k\Omega$

$V_x = V_3 - V_o$

$V_1 = 12V$

$V_2 = -2V_x$

at V_3 : $$\frac{V_3 - V_1}{R_1} + \frac{V_3 - V_2}{R_3} + \frac{V_3 - V_o}{R_4} = 0$$

at V_o : $$\frac{V_3 - V_o}{R_4} + 2\times10^{-3} = \frac{V_o}{R_5}$$

Solve for V_o : $\boxed{V_o = 2.5V}$

3.83 Solve for the assigned mesh currents in the network in Fig. P3.83.

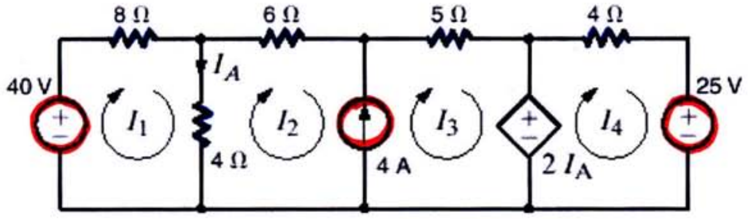
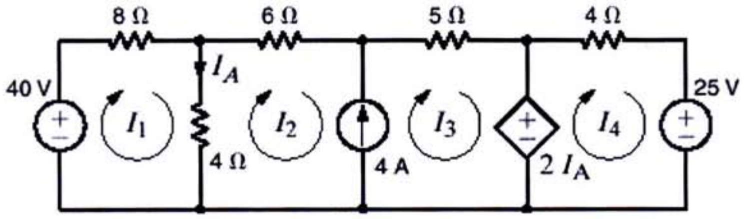


Figure P3.83

SOLUTION:



KCL: $I_1 = I_A + I_2$

$I_A = I_1 - I_2$

KVL: $8I_1 + 4I_A = 40$

$8I_1 + 4(I_1 - I_2) = 40$

$\boxed{12I_1 - 4I_2 = 40}$

KVL: $2I_A = 4I_4 + 25$

$2(I_1 - I_2) = 4I_4 + 25$

$\boxed{2I_1 - 2I_2 - 4I_4 = 25}$

KVL: $8I_1 + 6I_2 + 5I_3 + 4I_4 + 25 = 40$

$\boxed{8I_1 + 6I_2 + 5I_3 + 4I_4 = 15}$

KCL: $I_2 + 4 = I_3$

$\boxed{-I_2 + I_3 = 4}$

$$12I_1 - 4I_2 + 0I_3 + 0I_4 = 40$$
$$2I_1 - 2I_2 + 0I_3 - 4I_4 = 25$$
$$8I_1 + 6I_2 + 5I_3 + 4I_4 = 15$$
$$0I_1 - I_2 + I_3 + 0I_4 = 4$$

$I_1 = 2.97A$

$I_2 = -1.08A$

$I_3 = 2.92A$

$I_4 = -4.22A$

3.84 Using the assigned mesh currents shown in Fig. P3.84 solve for the power supplied by the dependent voltage source.

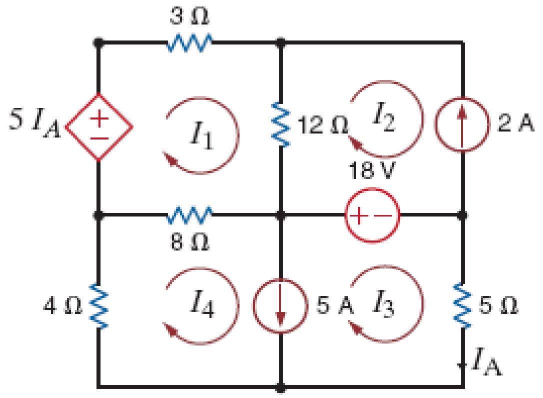
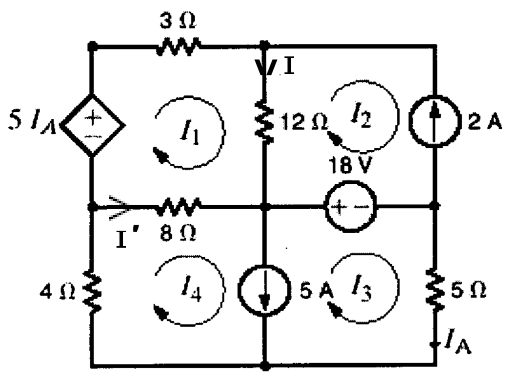


Figure P3.84

SOLUTION:



KCL: $I_1 = I + I_2$

$I = I_1 - I_2$

KCL: $I_4 = I' + I_1$

$I' = I_4 - I_1$

KVL: $3I_1 + 12I + 8(-I') = 5I_A$

$I_A = I_3$

$3I_1 + 12(I_1 - I_2) - 8(I_4 - I_1) = 5I_3$

$$\boxed{23I_1 - 12I_2 - 5I_3 - 8I_4 = 0}$$

KVL: $8I' + 5I_3 + 4I_4 + 18 = 0$

$8(I_4 - I_1) + 5I_3 + 4I_4 = -18$

$$\boxed{-8I_1 + 5I_3 + 12I_4 = -18}$$

KCL: $I_3 + 5 = I_4$

$I_2 = -2A$ $\boxed{I_3 - I_4 = -5}$

$\boxed{23I_1 - 5I_3 - 8I_4 = -24}$

$$23I_1 - 5I_3 - 8I_4 = -24$$
$$-8I_1 + 5I_3 + 12I_4 = -18$$
$$0I_1 + I_3 - I_4 = -5$$

$I_1 = -2.59A$

$I_3 = -5.8A$

$I_4 = -0.8A$

and $I_2 = -2A$

$\therefore P_{5IA} = (5 \times -5.8)(2.59) = 75W$

3.85 Determine V_0 in the network in the Fig. P3.85 using loop analysis.

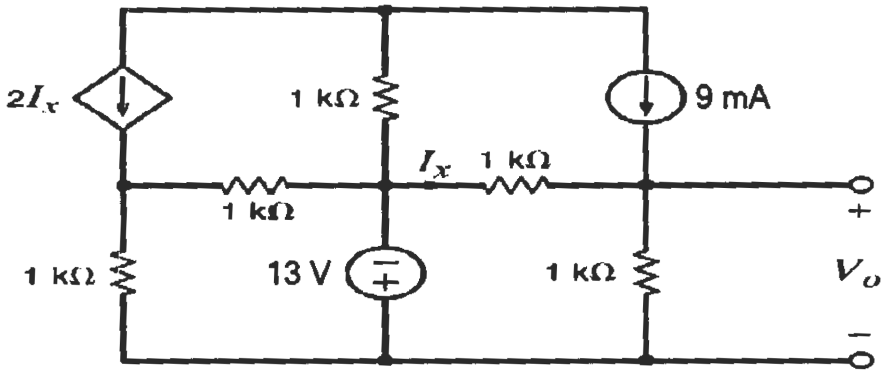
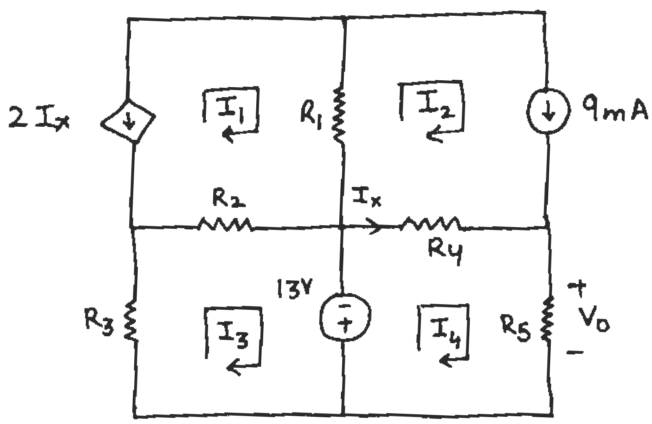


Figure P3.85

Solution: 3.85



$R_1 = R_2 = R_3 = R_4 = R_5 = 1\,k\Omega$

$I_2 = 9\,mA$

$I_x = (I_4 - I_2)$

$I_1 = -2I_x$

$= -2(I_4 - I_2)$

$V_0 = I_4 R_5$

KVL @ I_4: $13 + (I_4 - I_2)R_4 + I_4 R_5 = 0$

$13 + 10^3 I_4 - 10^3 I_2 + 10^3 I_4 = 0$

$I_4 = -2 \times 10^{-3}\,A$

$V_0 = I_4 R_5 = -2\times10^{-3} \times 1 \times 10^3$

$\boxed{V_0 = -2.00\,V}$

3.86 Using loop analysis, find V_o in the network in Fig. P3.86.

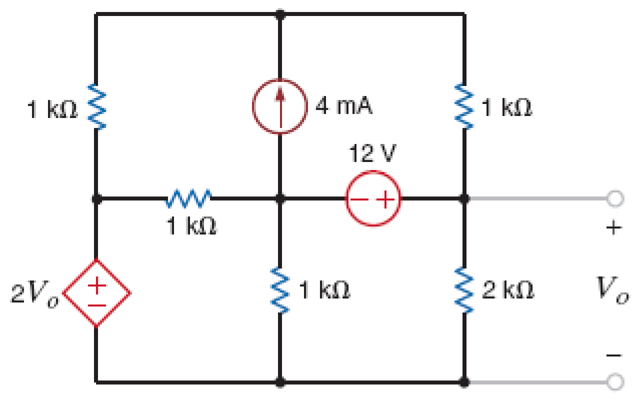
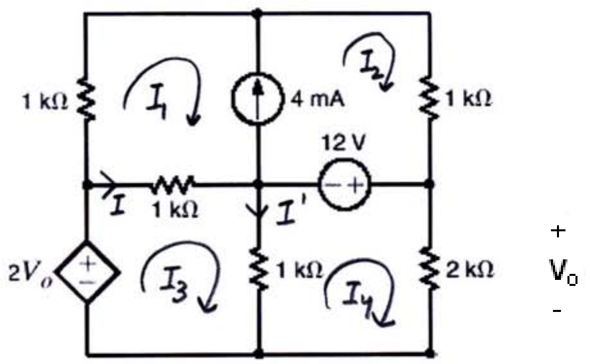


Figure P3.86

SOLUTION:



$$KCL: I_1 + 4m = I_2$$

$$\boxed{I_1 - I_2 = -4m}$$

$$KCL: I_3 = I + I_1$$

$$I = I_3 - I_1$$

$$KCL: I' + I_4 = I_3$$

$$I' = I_3 - I_4$$

$$KVL: 2kI_4 + 1k(-I') = 12$$

$$-1k(I_3 - I_4) + 2kI_4 = 12$$

$$\boxed{-1kI_3 + 3kI_4 = 12}$$

KVL: $1kI + 1kI' = 2V_0$

$V_0 = 2k I_4$

$1k(I_3 - I_1) + 1k(I_3 - I_4) = 2(2k I_4)$

$\boxed{-1kI_1 + 2kI_3 - 5kI_4 = 0}$

KVL: $2V_0 = 1kI_1 + 1kI_2 + 2kI_4$

$V_0 = 2kI_4$

$\boxed{1kI_1 + 1kI_2 - 2kI_4 = 0}$

$I_1 - I_2 + 0I_3 + 0I_4 = -4m$

$0I_1 + 0I_2 - 1kI_3 + 3kI_4 = 12$

$-1kI_1 + 0I_2 + 2kI_3 - 5kI_4 = 0$

$1kI_1 + 1kI_2 + 0I_3 - 2kI_4 = 0$

In the matrix form the equations canbe represented/restructed as:

$$\begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 2 & 0 & -2 \\ 0 & 0 & 4 & -12 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} -4 \\ 4 \\ -4 \\ 44 \end{bmatrix}$$

$V_0 = \infty$

Since there are only 3 independent equations for 4 unknowns (I1 to I4), it can be not be solved for a unique solutions.

This is because current equations are contradictory.

$\therefore V_0 =$ not defined (open circuit).

3.87 Using loop analysis, find V_o in the circuit in Fig. P3.87.

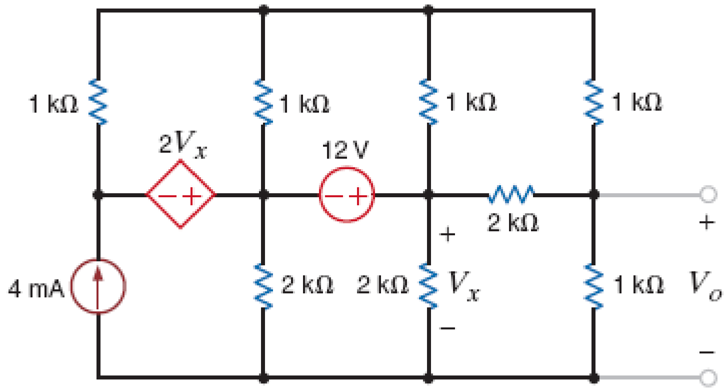
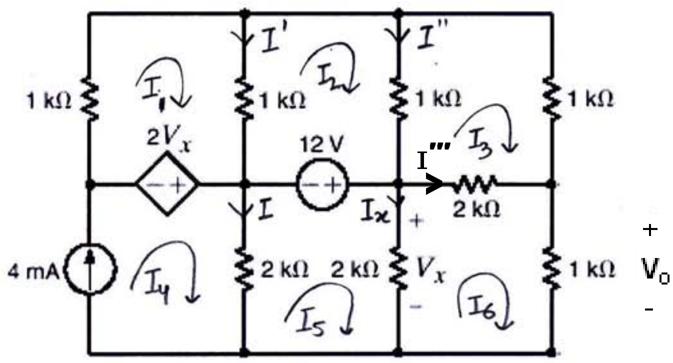


Figure P3.87

SOLUTION:



KCL: $I_1 = I' + I_2$

$I' = I_1 - I_2$

KCL: $I_2 = I'' + I_3$

$I'' = I_2 - I_3$

KCL: $I + I_5 = I_4$

$I = I_4 - I_5$

KCL: $I_x + I_6 = I_5$

$I_x = I_5 - I_6$

KCL: $I_3 + I''' = I_6$

$I''' = I_6 - I_3$

KVL: $2V_x + 1kI_1 + 1kI' = 0$

$$V_x = I_x(2k) = (I_5 - I_6)2k$$
$$2(2k)(I_5 - I_6) + 1kI_1 + 1k(I_1 - I_2) = 0$$
$$4kI_5 - 4kI_6 + 2kI_1 - 1kI_2 = 0$$

$$\boxed{2kI_1 - 1kI_2 + 4kI_5 - 4kI_6 = 0}$$

KVL: $12 + 1k(-I') + 1kI'' = 0$
$$-1k(I_1 - I_2) + 1k(I_2 - I_3) = -12$$
$$-1kI_1 + 2kI_2 - 1kI_3 = -12$$

KVL: $1k(-I'') + 1kI_3 + 2k(-I''') = 0$
$$-1k(I_2 - I_3) + 1kI_3 - 2k(I_6 - I_3) = 0$$
$$\boxed{-1kI_2 + 4kI_3 - 2kI_6 = 0}$$

KVL: $12 = 2k(-I) + 2kI_x$
$$-2k(I_4 - I_5) + 2k(I_5 - I_6) = 12$$
$I_4 = 4mA$
$$\boxed{4kI_5 - 2kI_6 = 20}$$

KVL: $2kI''' + 1kI_6 + 2k(-I_x) = 0$
$$2k(I_6 - I_3) + 1kI_6 - 2k(I_5 - I_6) = 0$$
$$\boxed{-2kI_3 - 2kI_5 + 5kI_6 = 0}$$

$$2kI_1 - 1kI_2 + 0I_3 + 4kI_5 - 4kI_6 = 0$$
$$-1kI_1 + 2kI_2 - 1kI_3 + 0I_5 + 0I_6 = -12$$
$$0I_1 - 1kI_2 + 4kI_3 + 0I_5 - 2kI_6 = 0$$
$$0I_1 + 0I_2 + 0I_3 + 4kI_5 - 2kI_6 = 20$$
$$0I_1 + 0I_2 - 2kI_3 - 2kI_5 + 5kI_6 = 0$$

$$I_1 = -18mA$$
$$I_2 = -17mA$$
$$I_3 = -4mA$$
$$I_5 = 5.25mA$$
$$I_6 = 0.5mA$$

$$V_o = 1k(I_6) = 1k(0.5m)$$
$$V_o = 0.5V$$

3.88 Use loop analysis to determine I_0 in the circuit in the Fig. P3.88.

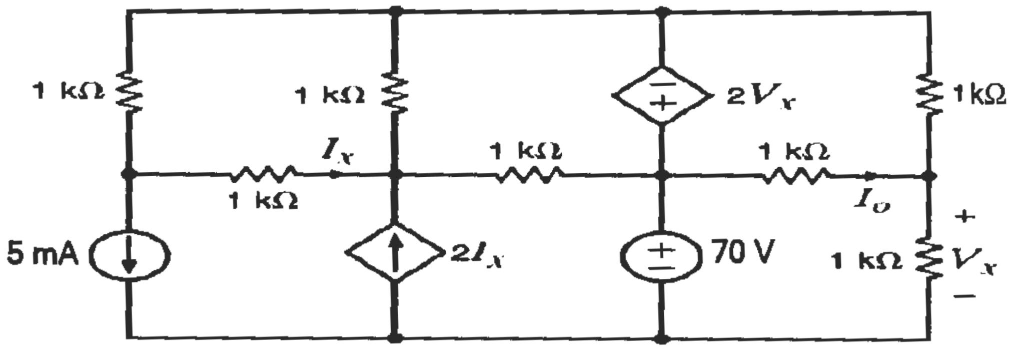
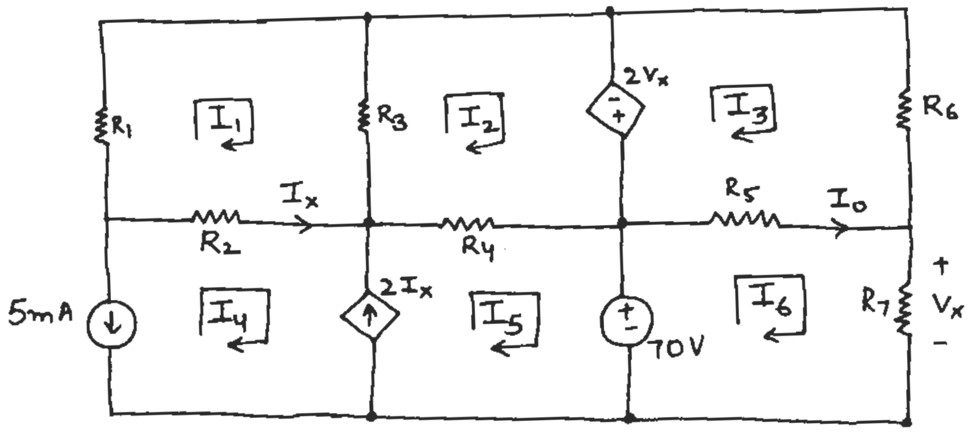


Figure P3.88

Solution: 3.88



$R_1 = R_2 = R_3 = R_4 = R_5 = R_6 = R_7 = 1\,k\Omega$

$I_4 = 5mA$

$2I_x = I_5 - I_4$

$I_x = I_4 - I_1$

$I_0 = I_6 - I_3$

$V_x = I_6 R_7$

KVL @ I_1: $I_1 R_1 + (I_1 - I_2) R_3 + (I_1 - I_4) R_2 = 0$

$3I_1 - I_2 = 5 \times 10^{-3}$

KVL @ I_2: $(I_2 - I_1)R_3 - 2V_x + (I_2 - I_5)R_4 = 0$

$$-I_1 + 2I_2 - I_5 - 2I_6 = 0$$

KVL @ I_3: $2V_x + I_3 R_6 + (I_3 - I_6)R_5 = 0$

$$2I_3 + I_6 = 0 \quad \text{—— } ①$$

KVL @ I_6: $-70 + (I_6 - I_3)R_5 + I_6 R_7 = 0$

$$-I_3 + 2I_6 = 70 \times 10^{-3} \quad \text{—— } ②$$

From equations ① and ②, we get

$$I_6 = 28 \text{ mA}$$

Substituting the value of I_6 in ①, we get

$$2I_3 = -28 \times 10^{-3}$$

$$I_3 = -14 \text{ mA}$$

$$I_O = I_6 - I_3$$

$$\boxed{I_O = 42.0 \text{ mA}}$$

3.89 Using loop analysis, find I_o in the circuit in Fig. P3.89.

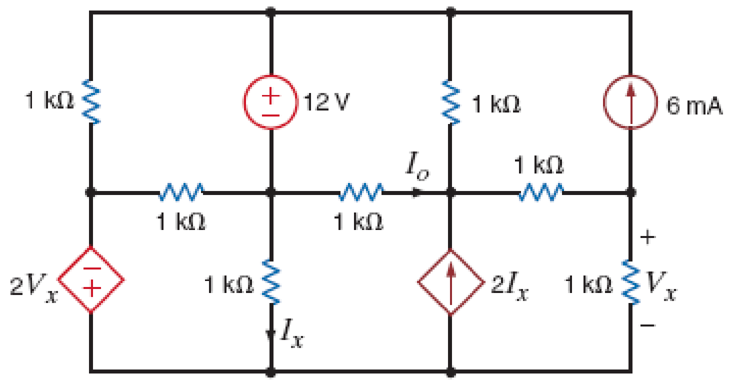
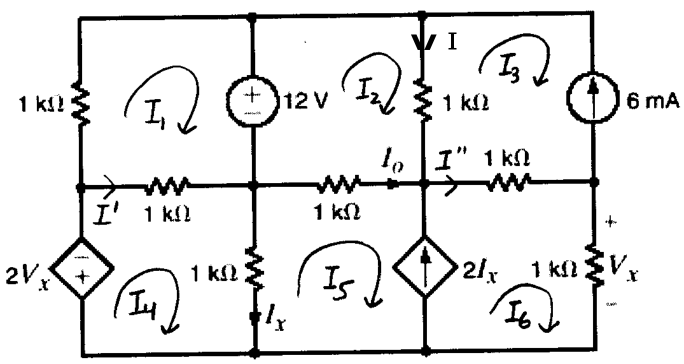


Figure P3.89

SOLUTION:



KCL: $I_2 = I + I_3$

$I = I_2 - I_3$

KCL: $I_4 = I' + I_1$

$I' = I_4 - I_1$

KCL: $I_3 + I'' = I_6$

$I'' = I_6 - I_3$

KCL: $I_5 + I_x = I_4$

$I_x = I_4 - I_5$

KCL: $I_0 + I + 2I_x = I''$

$I_0 = I'' - I - 2I_x = I_6 - I_3 - I_2 + I_3 - 2I_x$

$I_0 = I_6 - I_2 - 2(I_4 - I_5)$

$I_0 = -I_2 - 2I_4 + 2I_5 + I_6$

KVL: $1k\,I_1 + 12 + 1k(-I') = 0$

$1k\,I_1 - 1k\,(I_4 - I_1) = -12$

$$\boxed{2k\,I_1 - 1k\,I_4 = -12}$$

KVL: $1k\,I + 1k(-I_0) = 12$

$1k\,(I_2 - I_3) - 1k(-I_2 - 2I_4 + 2I_5 + I_6) = 12$

$$\boxed{2k\,I_2 - 1k\,I_3 + 2k\,I_4 - 2k\,I_5 - 1k\,I_6 = 12}$$

KVL: $2V_x + 1k\,I' + 1k\,I_x = 0$

$V_x = 1k\,I_6$

$2(1k\,I_6) + 1k(I_4 - I_1) + 1k\,(I_4 - I_5) = 0$

$$\boxed{-1k\,I_1 + 2k\,I_4 - 1k\,I_5 + 2k\,I_6 = 0}$$

KCL: $I_6 = 2I_x + I_5$

$I_5 - I_6 + 2(I_4 - I_5) = 0$

$$\boxed{2I_4 - I_5 - I_6 = 0}$$

KVL: $2V_x + 1k\,I' + 1k\,I_0 + 1k\,I'' + 1k\,I_6 = 0$

$2(1k\,I_6) + 1k(I_4 - I_1) + 1k(-I_2 - 2I_4 + 2I_5 + I_6) + 1k(I_6 - I_3) + 1k\,I_6$

$$\boxed{-1k\,I_1 - 1k\,I_2 - 1k\,I_3 - 1k\,I_4 + 2k\,I_5 + 5k\,I_6 = 0}$$

$I_3 = -6\,mA$

$$\boxed{2k\,I_2 + 2k\,I_4 - 2k\,I_5 - 1k\,I_6 = 6}$$

$$\boxed{-1k\,I_1 - 1k\,I_2 - 1k\,I_4 + 2k\,I_5 + 5k\,I_6 = -6}$$

$$2kI_1 + 0I_2 - 1kI_4 + 0I_5 + 0I_6 = -12$$
$$0I_1 + 2kI_2 + 2kI_4 - 2kI_5 - 1kI_6 = 6$$
$$-1kI_1 + 0I_2 + 2kI_4 - 1kI_5 + 2kI_6 = 0$$
$$0I_1 + 0I_2 + 2I_4 - I_5 - I_6 = 0$$
$$-1kI_1 - 1kI_2 - 1kI_4 + 2kI_5 + 5kI_6 = -6$$

$$I_1 = -6.48mA$$
$$I_2 = 3.12mA$$
$$I_4 = -0.96mA$$
$$I_5 = 0.24mA$$
$$I_6 = -2.16mA$$
$$I_0 = -I_2 - 2I_4 + 2I_5 + I_6$$
$$I_0 = -3.12m - 2(-0.96m) + 2(0.24m) - 2.16m$$
$$I_0 = -2.88mA$$

3.90 Use mesh analysis to determine the power delivered by the independent 3-V source in the network in Fig. P3.90.

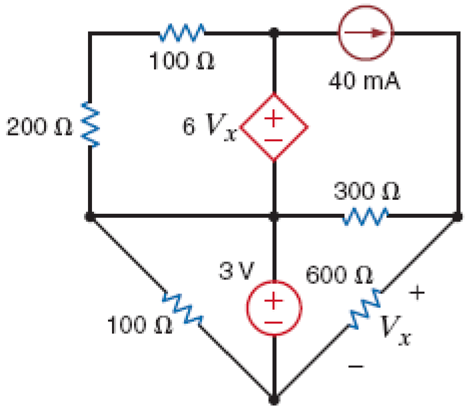
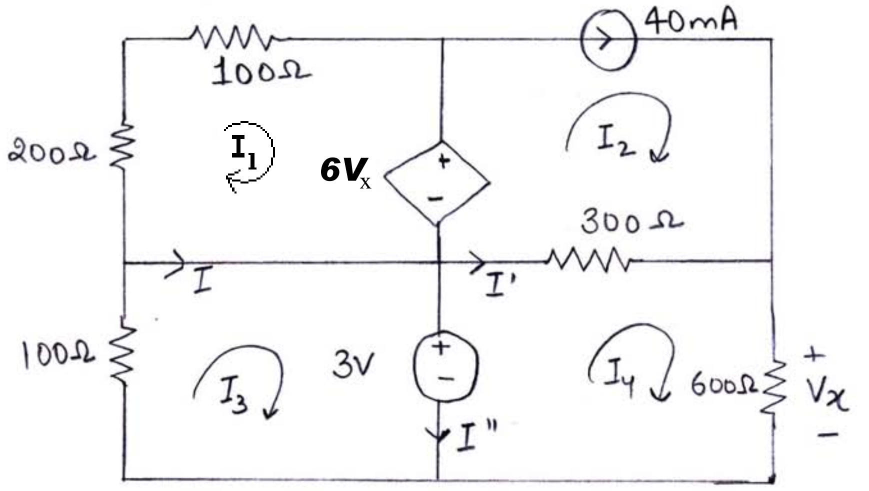


Figure P3.90

SOLUTION:



$$I_2 = 40mA$$

KCL: $I_3 = I + I_1$

$$I = I_3 - I_1$$

KCL: $40m + I' = I_4$

$$I' = I_4 - 40m$$

KVL: $200 I_1 + 100 I_1 + 6V_x = 0$

$$V_x = 600 I_4$$

$$300 I_1 + 3600 I_4 = 0$$

KVL: $100 I_3 + 3 = 0$

$I_3 = -30\,mA$

KVL: $3 = 300I' + 600I_4$

$600I_4 + 300(I_4 - 40m) = 3$

$900I_4 = 15$

$I_4 = 16.67\,mA$

KCL: $I_4 + I'' = I_3$

$I'' = I_3 - I_4$

$P_{3V} = I''(3) = 3(I_3 - I_4)$

$P_{3V} = 3(-30m - 16.67\,m)$

$P_{3V} = -140.01\,mW$

$P_{3V} = 140.01\,mW$

3.91 Use mesh analysis to find the power delivered by the current-controlled voltage source in the circuit in Fig. P3.91.

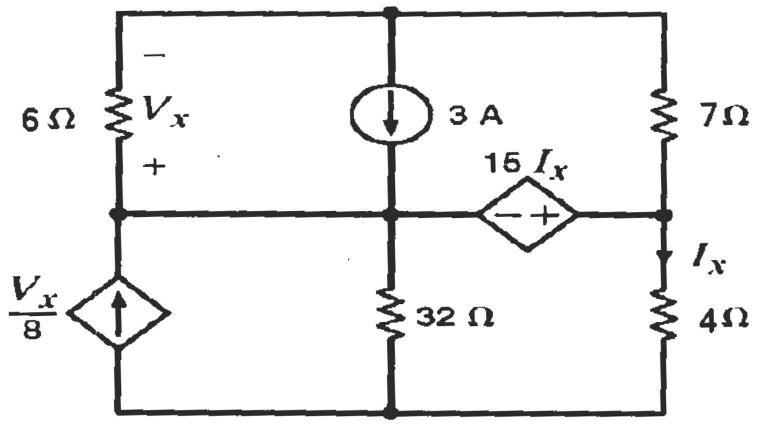
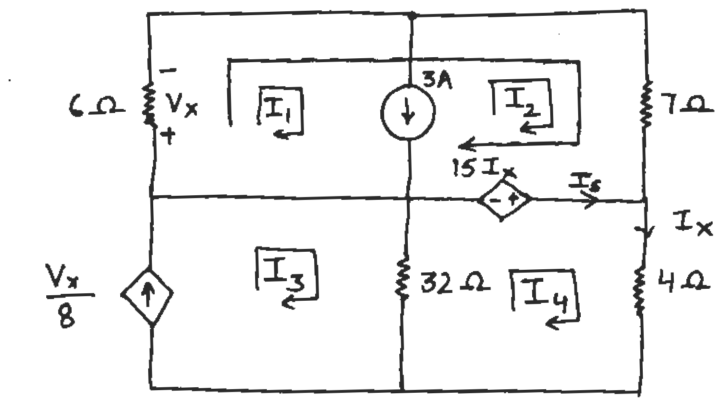


Figure P3.91

Solution: 3.41



$I_1 - I_2 = 3$ — ①

$V_x = 6 I_1$

$I_s = I_4 - I_2$

$I_x = I_4$

$I_3 = \frac{V_x}{8} = \frac{3}{4} I_1$

KVL @ I_4 : $32(I_4 - I_3) - 15 I_x + 4 I_4 = 0$

$21 I_4 - 32 I_3 = 0$

$I_4 = 1.52\ I_3$

KVL @ supermesh : $6 I_1 + 7 I_2 + 15 I_x = 0$

$$23.18 I_1 + 7 I_2 = 0 \quad \text{—— } (2)$$

From equations (1) and (2), we get

$$I_1 = 0.696 \text{ A}$$

$$I_3 = \frac{3}{4} I_1 = 0.522 \text{ A}$$

$$I_4 = 1.52 I_3 = 0.793 \text{ A}$$

$$I_s = I_4 - I_2 = 3.09 \text{ A}$$

$$P_{CCVS} = (15 I_x) I_s$$

$$\boxed{P_{CCVS} = 37.0 \text{ W}}$$

3.92 Use nodal analysis to determine I_0 in the circuit in Fig. P3.92.

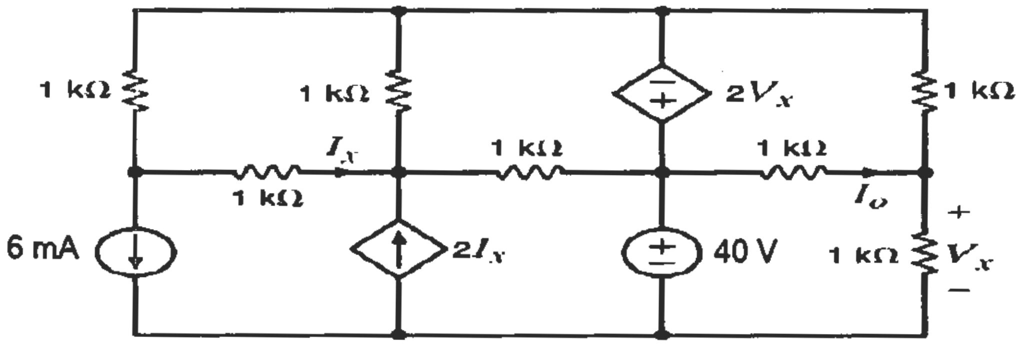
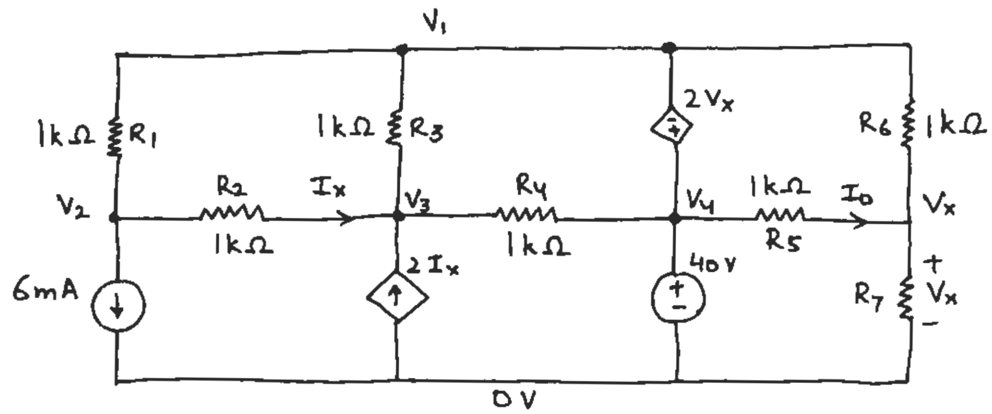


Figure P3.92

Solution: 3.92



$R_1 = R_2 = R_3 = R_4 = R_5 = R_6 = R_7 = 1\,k\Omega$

$V_4 = 40\ V$

$V_4 - V_1 = 2V_x$ ___ (1)

$\dfrac{V_2 - V_3}{R_2} = I_x$

$I_o = \dfrac{V_4 - V_x}{R_5}$

KCL @ V_2 : $\dfrac{V_2 - V_1}{R_1} + \dfrac{V_2 - V_3}{R_2} + 6 \times 10^{-3} = 0$

$-V_1 + 2V_2 - V_3 = -6$

KCL @ V_3 : $\dfrac{V_3 - V_2}{R_2} - 2I_x + \dfrac{V_3 - V_1}{R_3} + \dfrac{V_3 - V_4}{R_4} = 0$

$-V_1 - 3V_2 + 5V_3 = 40$ (Using $V_4 = 40\,V$)

KCL @ V_x : $\dfrac{V_x - V_4}{R_5} + \dfrac{V_x - V_1}{R_6} + \dfrac{V_x}{R_7} = 0$

$3V_x - V_4 - V_1 = 0$ — ②

Substituting equation ① in ②, we get

$3\left(\dfrac{V_4 - V_1}{2}\right) - V_4 - V_1 = 0$

$-\dfrac{5}{2}V_1 + \dfrac{1}{2}V_4 = 0$

$-5V_1 + 40 = 0$ (Using $V_4 = 40\,V$)

$V_1 = 8\,V$

$V_x = \dfrac{V_4 - V_1}{2} = \dfrac{40 - 8}{2}$

$V_x = 16\,V$

$I_O = \dfrac{V_4 - V_x}{R_5}$

$= \dfrac{40 - 16}{1 \times 10^3}$

$\boxed{I_O = 24.0\,mA}$

3.93 Use nodal analysis to find V_o in the circuit in Fig. P3.93.

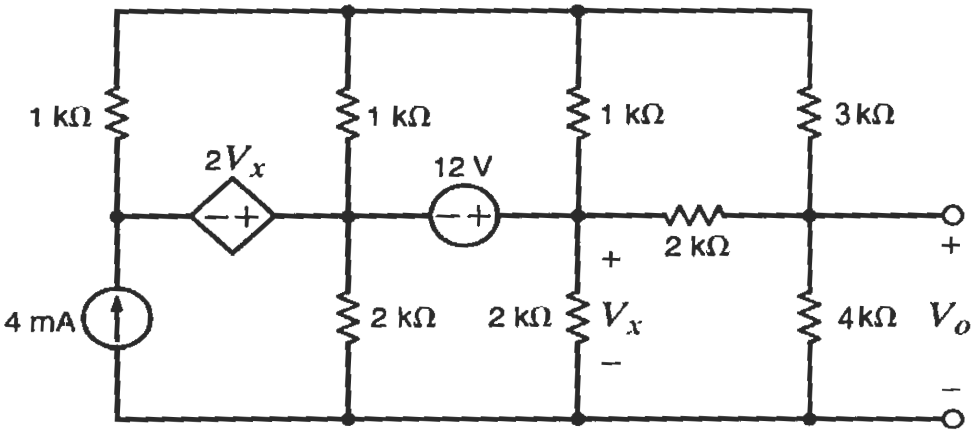
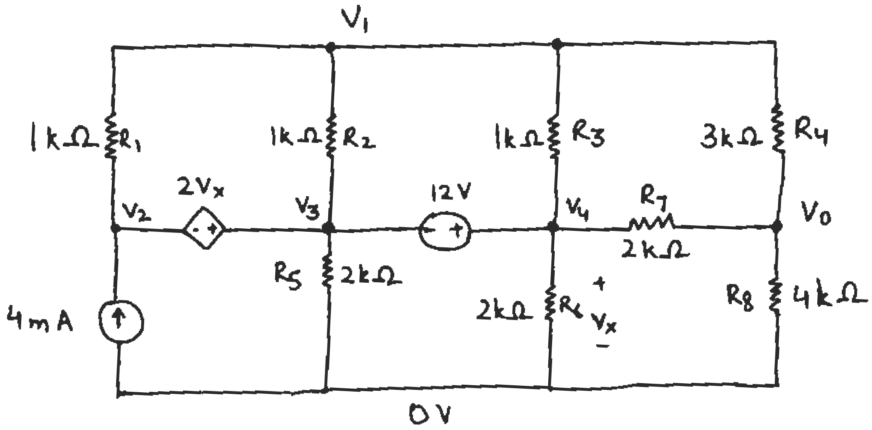


Figure P3.93

SOLUTION: 3.93



$R_1 = R_2 = R_3 = 1\,k\Omega$, $R_4 = 3\,k\Omega$, $R_5 = R_6 = R_7 = 2\,k\Omega$, $R_8 = 4\,k\Omega$

$V_3 - V_2 = 2V_x$ —— ①

$V_4 - V_3 = 12\,V$ —— ②

$V_x = V_4$ —— ③

KCL @ V_1 : $\dfrac{V_1 - V_2}{R_1} + \dfrac{V_1 - V_3}{R_2} + \dfrac{V_1 - V_4}{R_3} + \dfrac{V_1 - V_o}{R_4} = 0$

$-3V_4 - 3V_3 - 3V_2 + 10V_1 - V_o = 0$ —— ④

KCL @ reference : $\dfrac{V_3}{R_5} + \dfrac{V_4}{R_6} + \dfrac{V_o}{R_8} = 4 \times 10^{-3}$

$4V_3 + V_o = -8$ —— ⑤

KCL at V_0 : $\dfrac{V_0 - V_1}{3\times10^3} + \dfrac{V_0 - V_4}{2\times10^3} + \dfrac{V_0}{4\times10^3} = 0$

$$V_1 = \frac{13V_0 - 6V_4}{4} \quad \text{———} \quad (6)$$

Substituting equations (1), (2), (3) and (6) in (4), we get

$$-3V_4 - 3V_3 - 3V_2 + 10 \cdot \frac{13V_0 - 6V_4}{4} - V_0 = 0$$

$$-18(12 + V_3) - 3V_3 - 3(V_3 - 2(12 + V_3)) + \frac{63}{2}V_0 = 0$$

$$-4V_3 + 7V_0 = 32 \quad \text{———} \quad (7)$$

From equations (5) and (7) we get

$$\boxed{V_0 = 3.00\ \text{V}}$$

3.94 Find I_o in the network in Fig. P3.94 using nodal analysis.

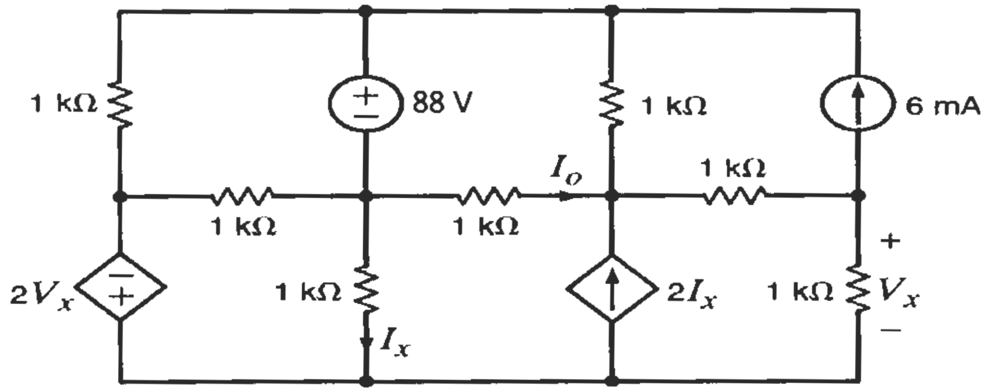
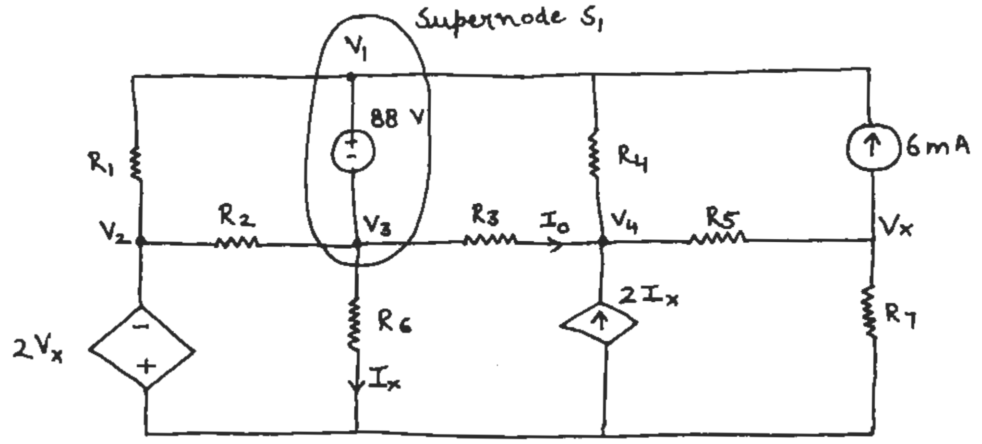


Figure P3.94

SOLUTION: 3.94



$$R_1 = R_2 = R_3 = R_4 = R_5 = R_6 = R_7 = 1k\Omega$$

$$I_x = \frac{V_3}{R_6} \quad — \quad (1)$$

$$V_1 - V_3 = 88\ V \quad — \quad (2)$$

$$V_2 = -2V_x \Rightarrow V_x = -\frac{V_2}{2}$$

$$\text{KCL @ } S_1 : \frac{V_1 - V_2}{R_1} + \frac{V_1 - V_4}{R_4} - 6\times10^{-3} + \frac{V_3 - V_2}{R_2} + \frac{V_3}{R_6} + \frac{V_3 - V_4}{R_3} = 0$$

$$2V_1 - 2V_2 + 3V_3 - 2V_4 = 6 \quad — \quad (3)$$

$$\text{KCL @ } V_4 : \frac{V_4 - V_3}{R_3} - 2I_x + \frac{V_4 - V_x}{R_5} + \frac{V_4 - V_1}{R_4} = 0$$

$$-2V_1 + V_2 - 6V_3 + 6V_4 = 0 \quad \text{—} \quad (4)$$

KCL @ V_x : $\frac{V_x - V_4}{R_5} + \frac{V_x}{R_7} + 6\times10^{-3} = 0$

$$V_2 + V_4 = 6 \quad \text{—} \quad (5)$$

Substituting equations (2) and (5) in (3), we get

$$2V_1 - 2V_2 + 3V_3 - 2V_4 = 6$$

$$V_3 = -31.6 \text{ V}$$

Substituting equations (2) and (5) in (4), we get

$$-2V_1 + V_2 - 6V_3 + 6V_4 = 0$$

$$V_4 = -16.56$$

$$I_o = \frac{V_3 - V_4}{R_3}$$

$$= \frac{-31.6 + 16.56}{10^3}$$

$$\boxed{I_o = -15.04 \text{ mA}}$$

4.1 An op-amp base amplifier has supply voltages of ± 5 V and a gain of 10. Sketch the input waveform from the output waveform in Fig. P4.1. What are (a) the minimum and (b) the maximum values of the input voltage?

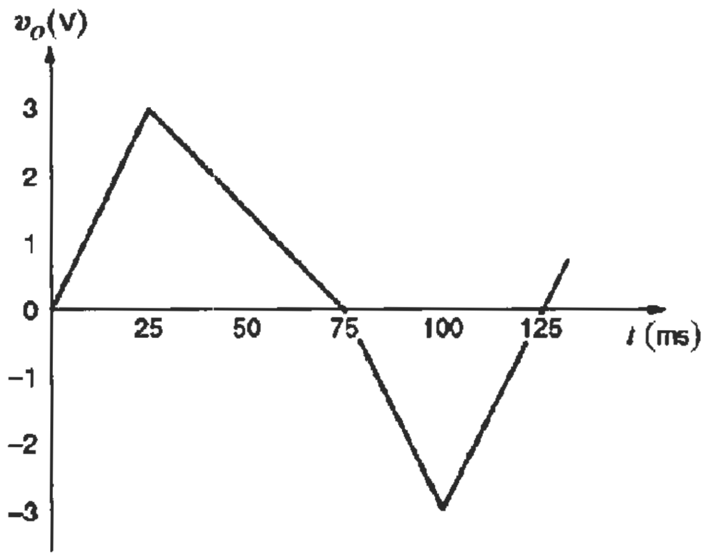


Figure P4.1

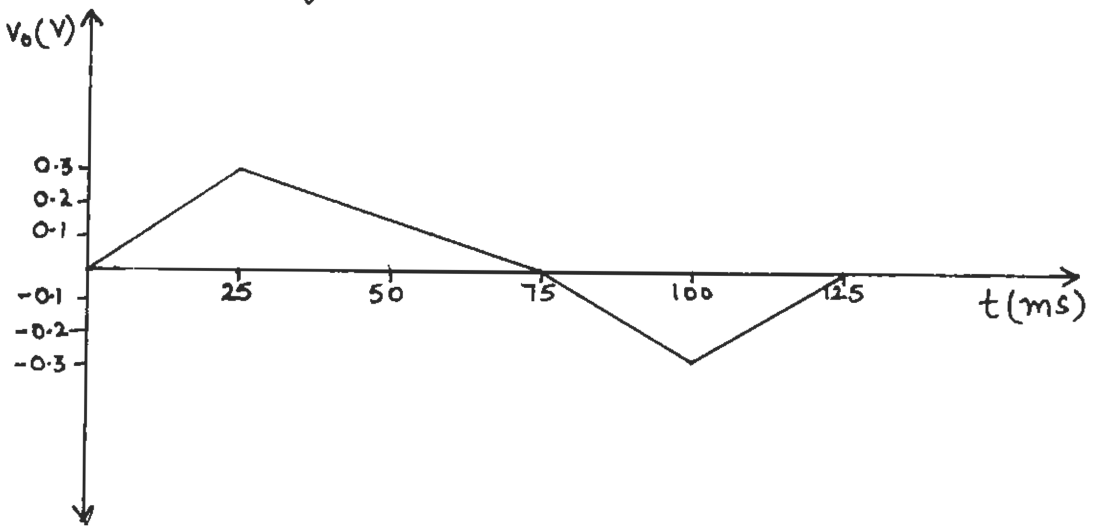
Solution: 4.1

$G = \frac{V_o}{V_s} \quad \therefore \quad V_s = \frac{V_o}{G}$

At $t = 25$ ms, $V_o = 3V$, $V_s = 0.3V$

At $t = 100$ ms, $V_o = -3V$, $V_s = -0.3V$

The input waveform is drawn



(a) The minimum value of the input voltage is -0.3 V.

(b) The maximum value of the input voltage is $+0.3$ V.

4.2 For an ideal op-amp, the voltage gain and input resistance are infinite while the output resistance is zero. What are the consequences for

(a) the op-amp's input voltage?

(b) the op-amp's input currents?

(c) the op-amp's output current?

SOLUTION:

(a) With infinite gain, an input voltage of zero will produce a finite output voltage,

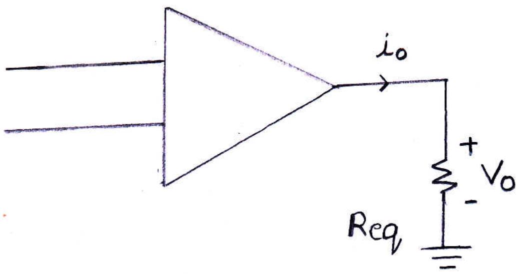
$V_{in} = 0V$ and, if V_{in} is a finite value the $V_{out} = \pm\infty$.

(b) No input current flows;

$R_{in} = \infty$

$i_{in} = 0A$

(c) With $R_{out} = 0\ \Omega$, the output current is limited only by external circuit variables,



$$i = \frac{V_o}{R_{eq}}$$

4.3 Revisit your answers in Problem 4.2 under the following nonideal scenarios.

(a) $R_{in} = \infty$, $R_{out} = 0$, $A_o \neq \infty$.

(b) $R_{in} = \infty$, $R_{out} > 0$, $A_o = \infty$.

(c) $R_{in} \neq \infty$, $R_{out} = 0$, $A_o = \infty$.

SOLUTION:

(a) $R_{in} = \infty$, $R_{out} = 0$, $A_0 \neq \infty$

If $R_{in} = \infty$, then $i_{in} = 0A$

If $R_{out} = 0$, then $i_{out} = \dfrac{V_{out}}{R_L}$ (R_2 = external resistor)

If $A_0 \neq \infty$, $V_{in} \neq 0$

(b) $R_{in} = \infty$, $R_{out} > 0$, $A_0 = \infty$

If $R_{in} = \infty$, $i_{in} = 0A$

If $A_0 = \infty$, $V_{in} = 0V$

If $R_{out} > 0$, i_{out} will be limited by both R_{out} and R_L

$$\Rightarrow i_{out} = \frac{V_{out}}{(R_L + R_{out})}$$

(c) $R_{in} \neq \infty$, $R_{out} = 0$, $A_0 = \infty$

If $A_0 = \infty$, $V_{in} = 0V$

If $R_{in} \neq \infty$, $i_{in} = \dfrac{V_{in}}{R_{in}}$

$i_{in} = 0A$ due to the fact that $V_{in} = 0V$

If $R_{out} = 0$, then i_{out} is limited only by R_L.

$$\Rightarrow i_{out} = \frac{V_{out}}{R_L}$$

4.4 Revisit the exact analysis of the inverting configuration in Section 4.3.

(a) Find an expression for the gain if $R_{in} = \infty$, $R_{out} = 0$, $A_o \neq \infty$.

(b) Plot the ratio of the gain in (a) to the ideal gain versus A_o for $1 \leq A_o \leq 1000$ for an ideal gain of -10.

(c) From your plot, does the actual gain approach the ideal value as A_o increases or decreases?

(d) From your plot, what is the minimum value of A_o if the actual gain is within 5% of the ideal case?

SOLUTION:

(a) From section 4.3:

$$\frac{V_o}{V_s} = \frac{-\frac{R_2}{R_1}}{1 - \frac{\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_{in}}\right)\left(\frac{1}{R_2} + \frac{1}{R_o}\right)}{\frac{1}{R_2}\left(\frac{1}{R_2} - \frac{A_o}{R_o}\right)}}$$

When $R_{in} = \infty$, $R_{out} = 0$, and $A_o \neq \infty$

$$\frac{1}{R_{in}} << \frac{1}{R_1} \quad \text{and} \quad \frac{1}{R_{in}} << \frac{1}{R_2}$$

$$\frac{1}{R_o} >> \frac{1}{R_2}$$

$$\frac{V_o}{V_s} = \frac{-\frac{R_2}{R_1}}{1 + \frac{\left(\frac{1}{R_1} + \frac{1}{R_2}\right)\frac{1}{R_o}}{\frac{1}{R_2}\left(\frac{A_o}{R_o}\right)}}$$

$$\frac{V_o}{V_s} = \frac{-\frac{R_2}{R_1}}{1 + \frac{\frac{R_2+R_1}{R_2 R_1}}{\frac{A_o}{R_2}}}$$

$$\frac{V_o}{V_s} = \frac{-\frac{R_2}{R_1}}{1 + \left(\frac{R_1+R_2}{R_1}\right)\frac{1}{A_o}}$$

$$\frac{V_O}{V_S} = \frac{-\frac{R_2}{R_1}}{1 + \frac{1}{A_O}\left(1 + \frac{R_2}{R_1}\right)}$$

(b)

$$A_{ideal} = \frac{-R_2}{R_1}$$

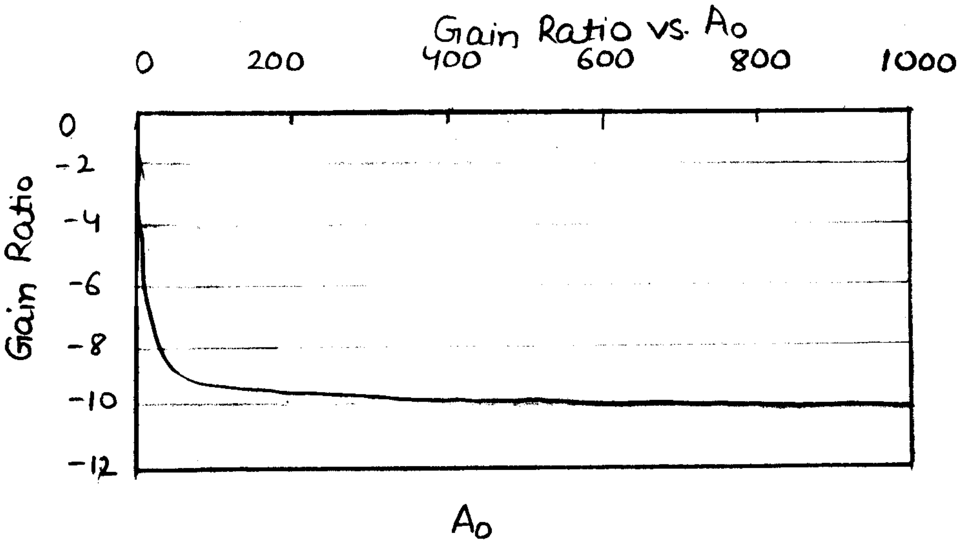
$$A_{ideal} = -10$$

$$A_{actual} = \frac{V_O}{V_S}$$

$$A_{actual} = \frac{-10}{1 + \frac{1}{A_O}(1+10)}$$

$$A_{actual} = \frac{-10}{1 + \frac{11}{A_O}}$$

$$1 \leq A_O \leq 1000$$



(c) When A_o increases, A_{actual} approaches A_{ideal}

(d) $$\frac{A_{actual}}{A_{ideal}} = \frac{\dfrac{-10}{1+\dfrac{11}{A_o}}}{-10}$$

$$\frac{\dfrac{-10}{1+\dfrac{11}{A_o}}}{-10} \leq 0.95$$

$$A_o \geq 209$$

4.5 Find an expression for the voltage gain of the inverting op–amp. If $R_{in} \neq \infty$, $R_{out} = 0$, $A_0 \neq \infty$. Find the gain if R_1=15Ω, R_2=10Ω, R_i=24Ω, A_0=15.

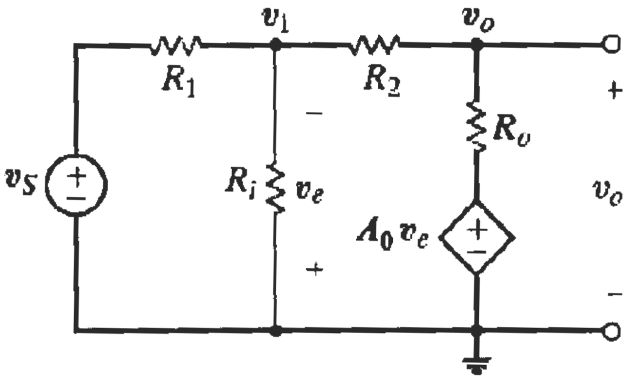


Figure P4.5

Solution: 4.5

Since $R_{in} \neq \infty$ and $A_o \neq \infty$, this is a non-ideal inverting op-amp.

Therefore, $$\frac{V_o}{V_s} = A_{actual} = \frac{-R_2/R_1}{1 - \dfrac{\left(\frac{1}{R_1}+\frac{1}{R_i}+\frac{1}{R_2}\right)\left(\frac{1}{R_2}+\frac{1}{R_o}\right)}{\frac{1}{R_2}\left(\frac{1}{R_2}-\frac{A_o}{R_o}\right)}}$$

For $R_o = 0$, $\frac{1}{R_o} \gg \frac{1}{R_2}$ and $\frac{A_o}{R_o} \gg \frac{1}{R_2}$

So, $$A_{actual} = \frac{-R_2/R_1}{1 + \dfrac{\left(\frac{1}{R_1}+\frac{1}{R_i}+\frac{1}{R_2}\right)}{A_o/R_2}}$$

$$A_{actual} = \frac{-R_2/R_1}{1 + \frac{1}{A_o}\left(\frac{R_2}{R_1}+\frac{R_2}{R_i}+1\right)} \quad \text{———} \quad (1)$$

$R_1 = 15\,\Omega$, $R_2 = 10\,\Omega$, $R_i = 24\,\Omega$, $A_o = 15$

From (1), we get

$$\boxed{A_{actual} = -0.585}$$

4.6 An op-amp based amplifier has ± 24 V supplies and a gain of -80. Over what input range is the amplifier linear?
Find (a) the minimum and (b) the maximum values.

Solution: 4.6

For linear operation

$$\frac{V_o}{V_{in}} = -80$$

Due to output limits, $V_{o(max)} = 24\,V$, $V_{o(min)} = -24\,V$

Therefore, input range of the amplifier over which the amplifier is linear is

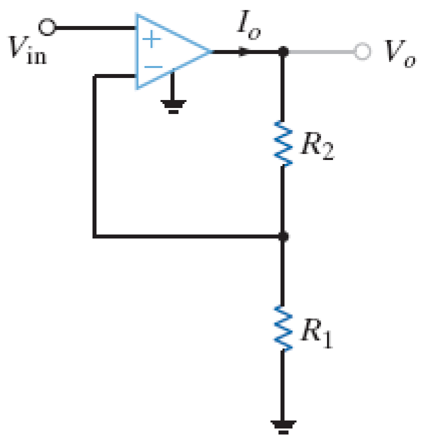
$$-\frac{24}{80} \leq V_{in} \leq \frac{24}{80}$$

$$-0.300\,V \leq V_{in} \leq 0.300\,V$$

$$\boxed{V_{in(min)} = -0.300\,V}$$

$$\boxed{V_{in(max)} = 0.300\,V}$$

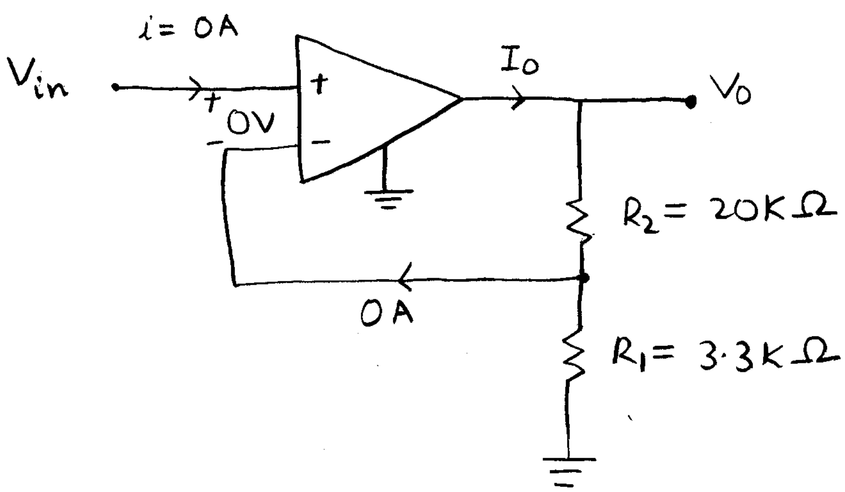
4.7 Determine the gain of the amplifier in Fig. P4.7. What is the value of I_o?



$R_2 = 20\ \text{k}\Omega$
$R_1 = 3.3\ \text{k}\Omega$
$V_{in} = 2\ \text{V}$

Figure P4.7

SOLUTION:



Non-inverting configuration:

$$\frac{V_o}{V_{in}} = 1 + \frac{R_2}{R_1}$$

$$\frac{V_o}{V_{in}} = 1 + \frac{20\times10^3}{3.3\times10^3}$$

$$\frac{V_o}{V_{in}} = 7.06$$

for $V_{in} = 2V$

$$V_0 = 7.06(2)$$
$$V_0 = 14.12\ V$$

$$I_0 = \frac{V_0}{R_1 + R_2}$$

$$I_0 = \frac{14.12}{3.3 \times 10^3 + 20 \times 10^3}$$

$$I_0 = 606\ \mu A$$

4.8 For the amplifier in Fig.P4.8, find (a) the gain (b) I_0.

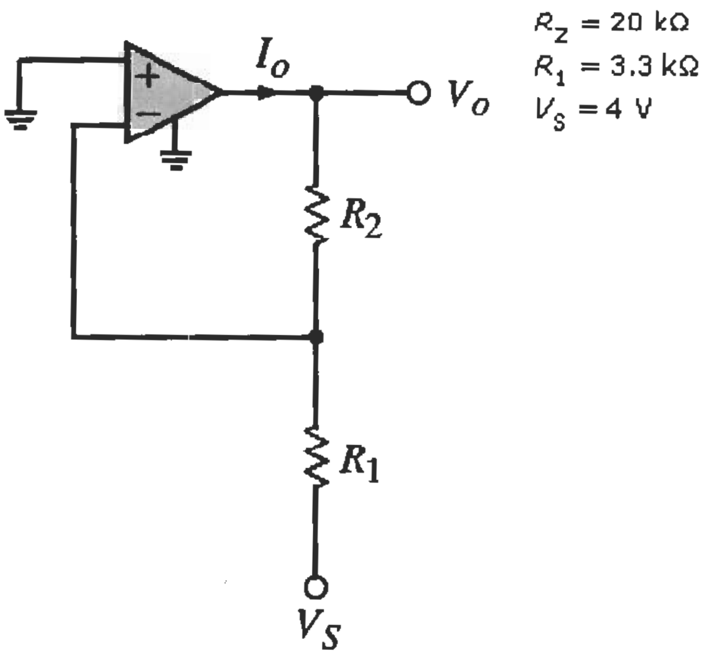


Figure P4.8

Solution: 4.8

(a) Basic inverting configuration,

$$G = \frac{V_o}{V_s} = -\frac{R_2}{R_1}$$

$$G = \frac{-20}{3.3} = -6.06$$

$$\boxed{G = -6.06}$$

(b) $I_o = \frac{V_o}{R_2}$

$V_o = -6.06\ V_s$

$V_o = -24.24\ V$

$I = \frac{-24.24}{20}$

$$\boxed{I = -1.212\ mA}$$

4.9 Using the ideal op-amp assumptions, determine the values of V_o and I_1 in Fig. P4.9.

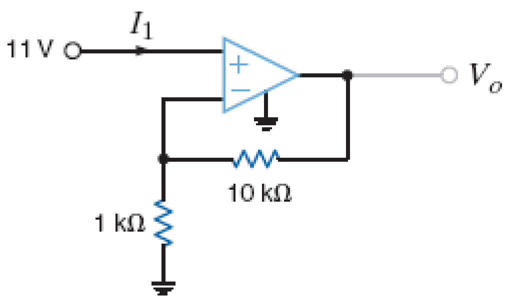
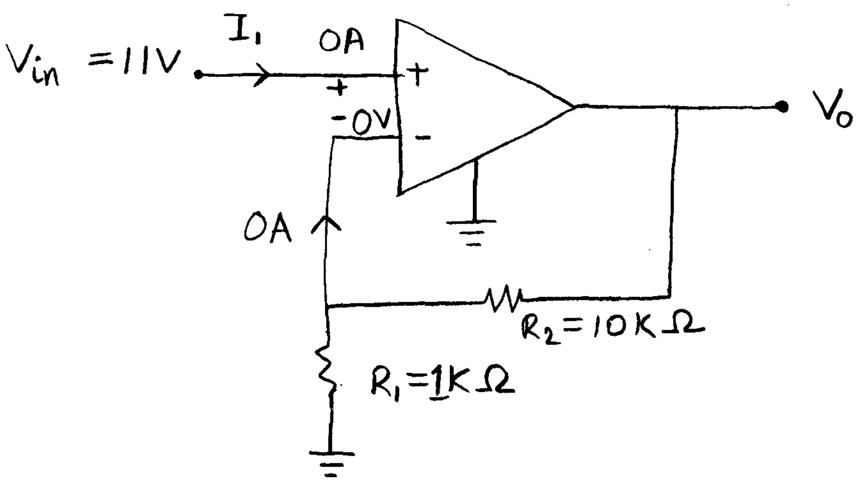


Figure P4.9

SOLUTION:



Non-inverting configuration:

$$\frac{V_o}{V_{in}} = 1 + \frac{R_2}{R_1} = 1 + \frac{10\times10^3}{1\times10^3}$$

$$\frac{V_o}{V_{in}} = 11$$

$$V_o = 11V_{in} = 11(11)$$

$$V_o = 121V$$

If $R_{in} = \infty$, then $I_{in} = 0$

$$I_i = 0A$$

4.10 Using the ideal op-amp assumptions, determine (a) I_1, (b) I_2 and (c) I_3 in Fig. P4.10.

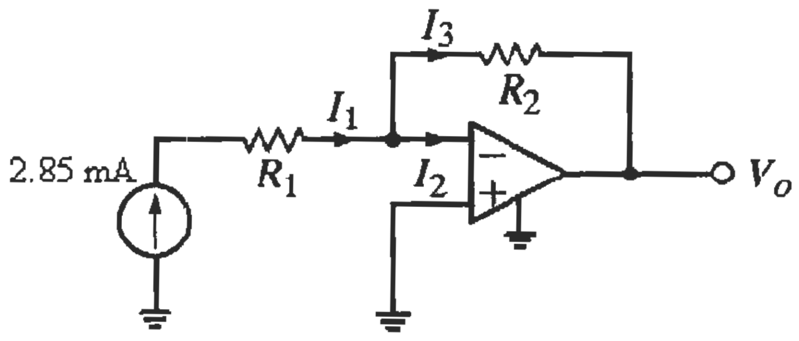


Figure P4.10

Solution: 4.10

For ideal op-amp assumption,

$\boxed{I_1 = 2.85 \text{ mA}}$

$\boxed{I_2 = 0}$

Applying KCL at the inverting terminal

$I_3 = I_1 - I_2$

$\boxed{I_3 = 2.85 \text{ mA}}$

4.11 In a useful application, the amplifier drives a load. The circuit in Fig. P4.11 models this scenario.

(a) Sketch the gain V_o/V_S for $10\ \Omega \le R_L \le \infty$.

(b) Sketch I_o for $10\ \Omega \le R_L \le \infty$ if $V_S = 0.1$ V.

(c) Repeat (b) if $V_S = 1.0$ V.

(d) What is the minimum value of R_L if $|I_o|$ must be less than 100 mA for $|V_S| < 0.5$ V?

(e) What is the current I_S if R_L is 100 Ω? Repeat for $R_L = 10$ kΩ.

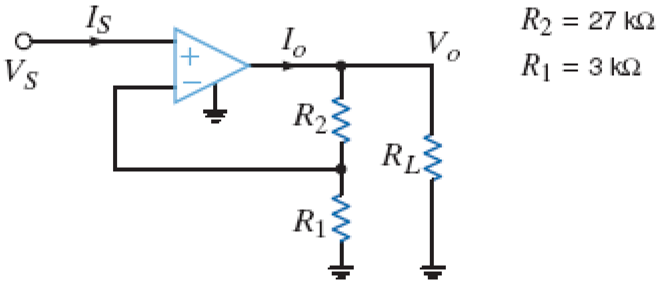
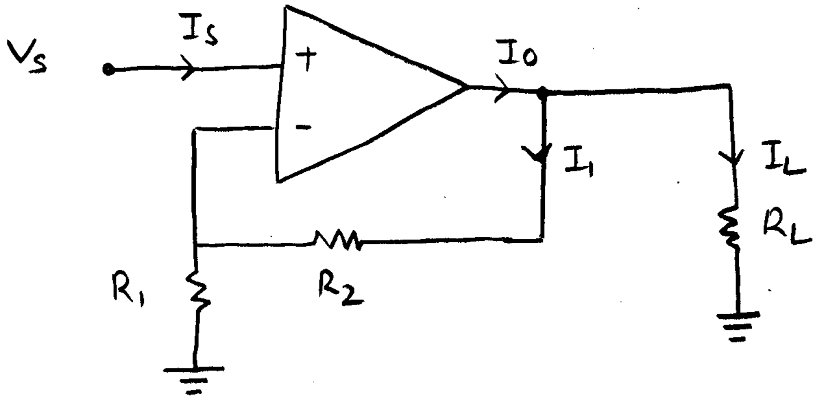


Figure P4.11

SOLUTION:

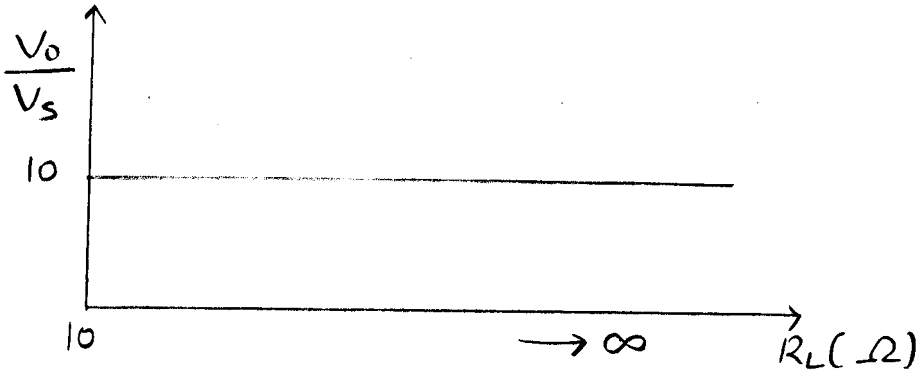


$$R_1 = 3K\Omega \quad , \quad R_2 = 27\,K\Omega$$

$$\frac{V_o}{V_s} = 1 + \frac{R_2}{R_1} = 1 + \frac{27 \times 10^3}{3 \times 10^3}$$

$$\frac{V_o}{V_s} = 10$$

(a)

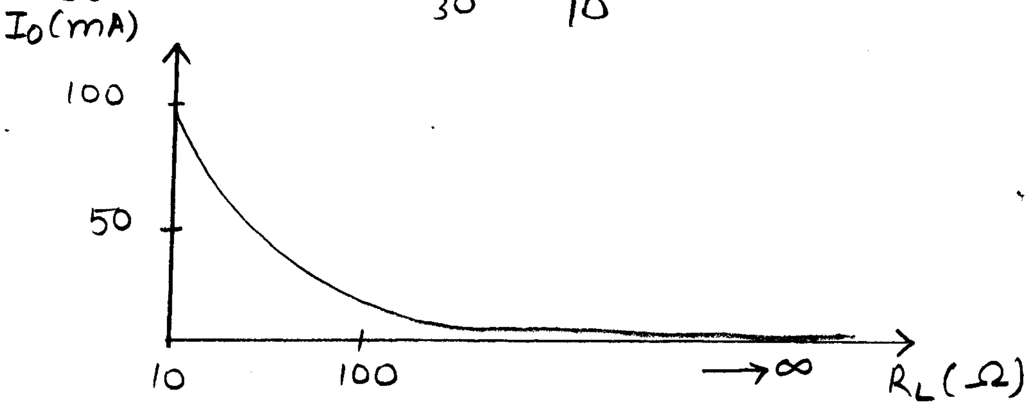


(b) $V_s = 0.1V$, $V_o = 10(0.1) = 1V$

$$I_o = I_L + I_1$$

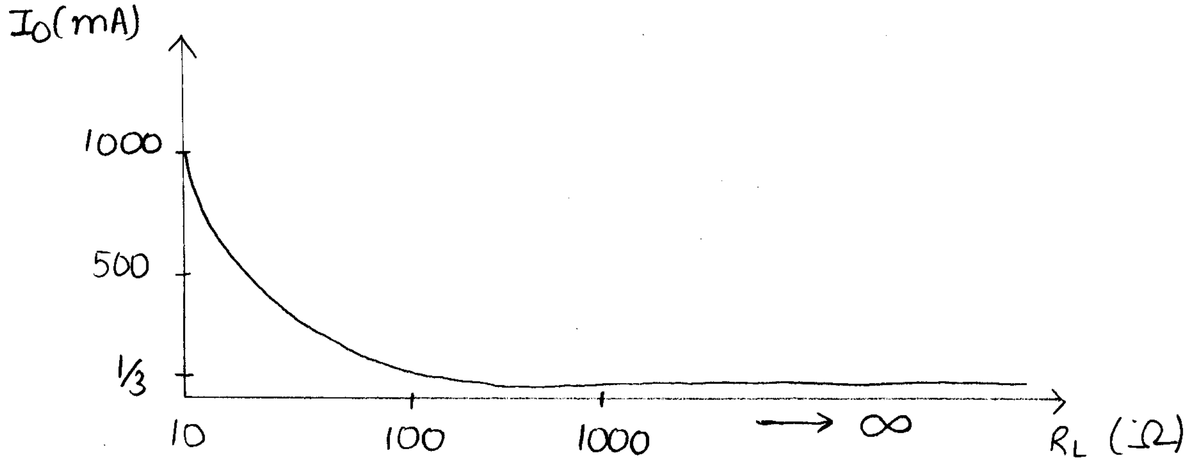
$$I_o = \frac{V_o}{30\times10^3} + \frac{V_o}{R_L}$$

$$\frac{10^{-3}}{30} + \frac{1}{\infty} \le I_o \le \frac{10^{-3}}{30} + \frac{1}{10} \Rightarrow \boxed{33.3\,\mu A \le I_o \le .10003A}$$



(c) $V_s = 1V$, $V_o = 10V$

$$I_o = \frac{10}{30\times10^3} + \frac{10}{R_L}$$



(d) $V_s = 0.5V$, $V_o = 5V$

$$I_o = \frac{5}{30\times10^3} + \frac{5}{R_L}$$

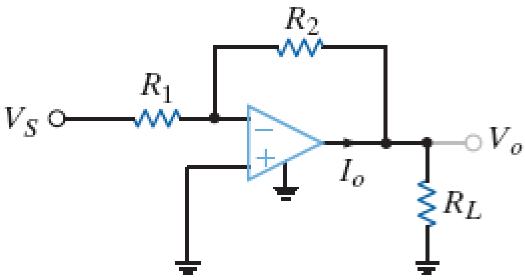
$$\frac{5}{30\times10^3} + \frac{5}{R_L} < 100\times10^{-3}$$

$$R_L > 50.1\,\Omega$$

(e) I_s flows into the non-inverting input of the op-amp

$I_s = 0$, the value of R_L doesn't matter.

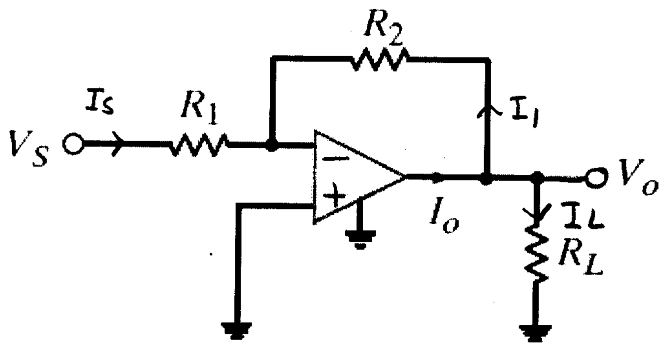
4.12 Repeat Problem 4.11 for the circuit in Fig. P4.12.



$R_2 = 27\ \text{k}\Omega$
$R_1 = 3\ \text{k}\Omega$

Figure P4.12

SOLUTION:



$R_1 = 3\ \text{K}\Omega$ and $R_2 = 27\ \text{K}\Omega$

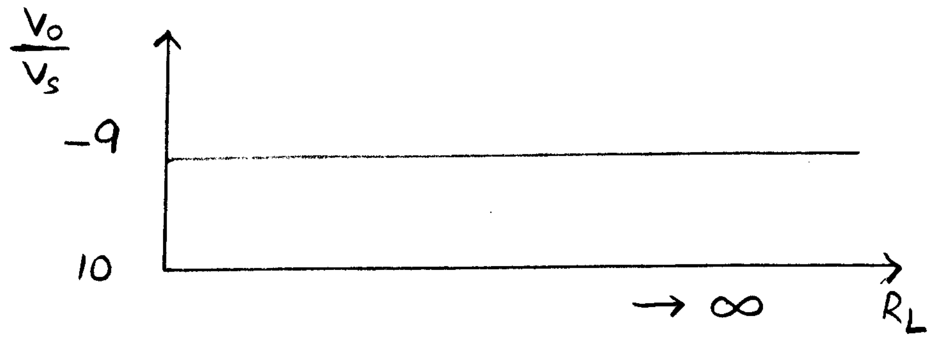
(a) $$V_o = \frac{-R_2}{R_1} V_s$$

$$V_o = \frac{-27\text{K}}{3\text{K}} V_s$$

$$V_o = -9 V_s$$

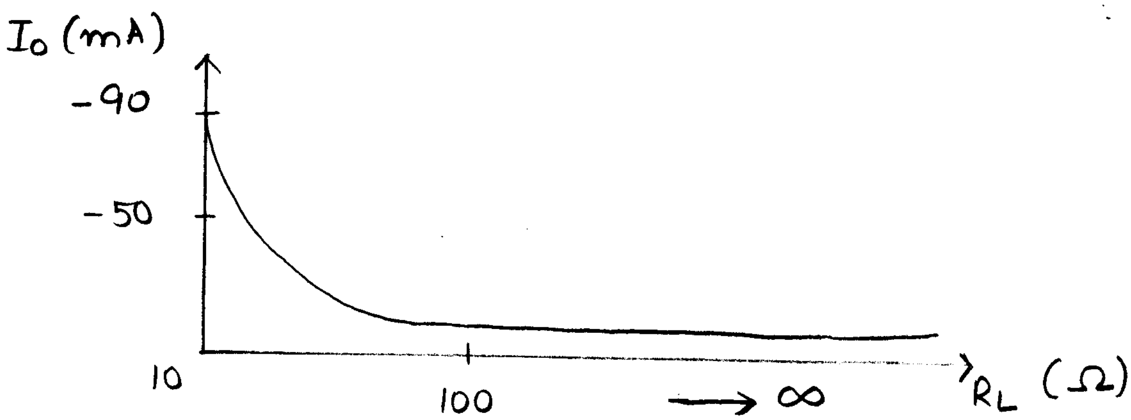
$$I_o = I_1 + I_L$$

$$I_o = \frac{V_o}{R_2} + \frac{V_o}{R_L}$$



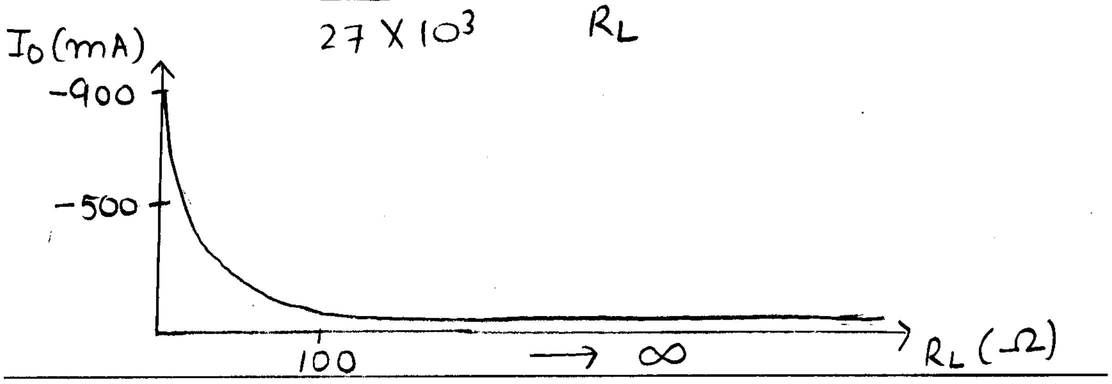
(b) $V_s = 0.1\text{ V}$, and $V_o = -0.9\text{V}$

$$I_o = \frac{-0.9}{27 \times 10^3} - \frac{0.9}{R_L}$$



(c) $V_s = 1\text{V}$, and $V_o = -9\text{V}$

$$I_o = \frac{-9}{27 \times 10^3} - \frac{9}{R_L}$$



(d) $I_0 = \frac{-9V_s}{27 \times 10^3} - \frac{9V_s}{R_L}$

at $V_S = 0.5V$

$|I_o| = \frac{-9(0.5)}{27 \times 10^3} - \frac{9(0.5)}{R_L}$

$|I_o| = \frac{4.5}{27 \times 10^3} + \frac{4.5}{R_L} < 100mA$

$R_L > 45.1\,\Omega$

(e) $I_s = \frac{V_s}{R_1}$

$I_s = \frac{V_s}{3000}$, I_s is independent of R_L

at $V_s = 0.5V$

$I_s = \frac{0.5}{3000}$

$I_s = 167\ \mu A$

4.13 The op-amp in the amplifier in Fig. P4.13 operates with ±15 V supplies and can output no more than 200 mA. What is the maximum gain allowable for the amplifier if the maximum value of V_s is 1 V?

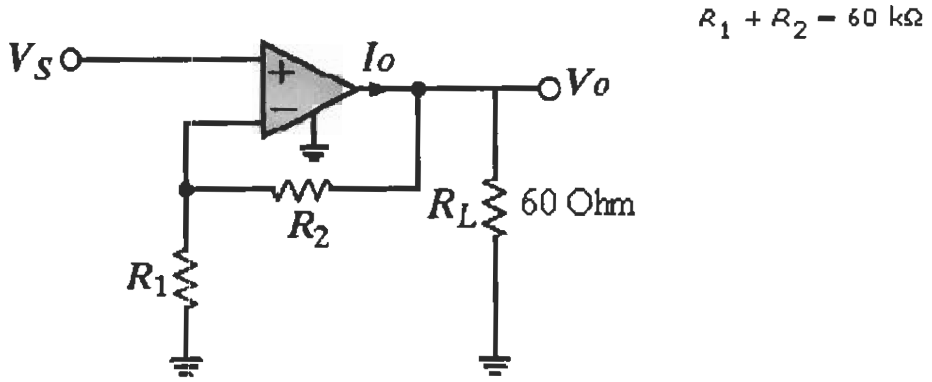


Figure P4.13

Solution: 4.13

Basic non-inverting configuration

$$A_v = \frac{V_o}{V_s} = 1 + \frac{R_2}{R_1} = \frac{R_1 + R_2}{R_1} = \frac{60 \times 10^3}{R_1} = \frac{6 \times 10^4}{R_1}$$

$$|V_o| = |V_s| \left(\frac{6 \times 10^4}{R_1}\right) \leq 15 \quad \text{[For linear operation]}$$

$$V_{s_{max}} = 1\text{V}$$

For $V_{s_{max}} = 1\text{V}$, $V_o = \frac{6 \times 10^4}{R_1}$

$$\text{Also, } I_o = \frac{V_o}{R_1 + R_2} + \frac{V_o}{R_L}$$

$$= \frac{6 \times 10^4}{R_1 \times 60 \times 10^3} + \frac{6 \times 10^4}{R_1 \times 60}$$

$$= \frac{1001}{R_1}$$

$$\therefore \frac{1001}{R_1} \leq 200 \text{ mA}$$

$$R_1 \geq \frac{1001}{200 \times 10^{-3}}$$

$$\therefore R_1 \geq 5005\ \Omega \text{ and } R_2 \leq 54995\ \Omega$$

$$Av_{max} = 1 + \frac{R_{2max}}{R_{1min}} = 1 + 10.988$$

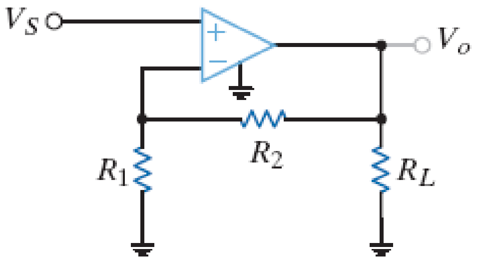
$$\boxed{Av_{max} = 12}$$

4.14 For the amplifier in Fig. P4.14. the maximum value of V_S is 2 V and the op-amp can deliver no more than 100 mA.

(a) If ±10 V supplies are used, what is the maximum allowable value of R_2?

(b) Repeat for ±3 V supplies.

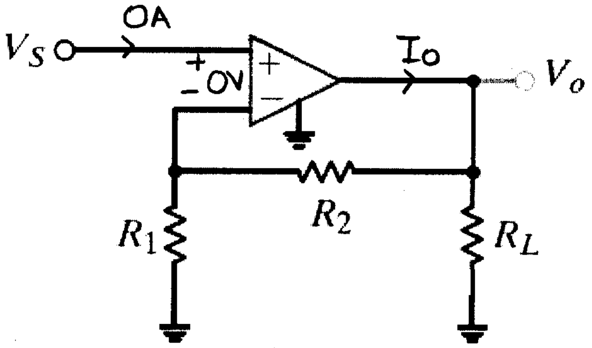
(c) Discuss the impact of the supplies on the maximum allowable gain.



R_L = 10 Ω
R_1 = 100 Ω

Figure P4.14

SOLUTION:



$R_1 = 100\,k\Omega$

$R_L = 10\,K\Omega$

(a) Non-inverting op-amp:

$$V_o = \left(1+\frac{R_2}{R_1}\right)V_S$$

$$I_o = \frac{V_o}{R_L \,||\, (R_1+R_2)}$$

for $V_S = 2V$

$$V_o = \left(1+\frac{R_2}{R_1}\right)(2)$$

$$\left(1+\frac{R_2}{R_1}\right)2 \leq 10$$

$$R_2 \leq 400k\Omega$$

$$I_O = \frac{10}{10\times10^3 \,||\, (100\times10^3 + 400\times10^3)}$$

$$I_O = 1.02\ mA \leq 100mA$$

$R_2 = 400k$ Ohms satisfies both current and voltage limit.

(b) $$V_O = \left(1+\frac{R_2}{R_1}\right)(2)$$

$$\left(1+\frac{R_2}{R_1}\right)(2) \leq 3$$

$$R_2 \leq 50K\Omega$$

$$I_O = \frac{3}{10\times10^3 \,||\, (100\times10^3 + 50\times10^3)}$$

$$I_O = 320\ \mu A$$

(c) For any value of V_S, AV_{max} is a linear function of the supply voltage. This relationship exists until the I_O limit is an issue. The limit on I_O is 100mA.

4.15 For the circuit in Fig. P4.15, find V_0, if $V_1 = 3\ V$ and $V_2 = 9\ V$.

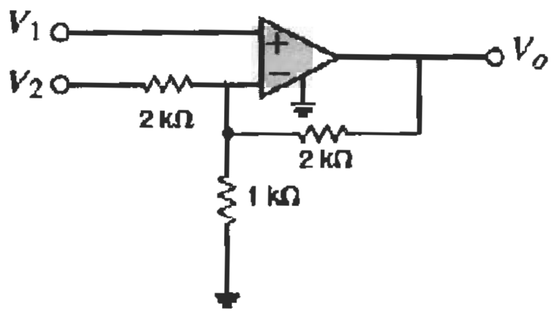
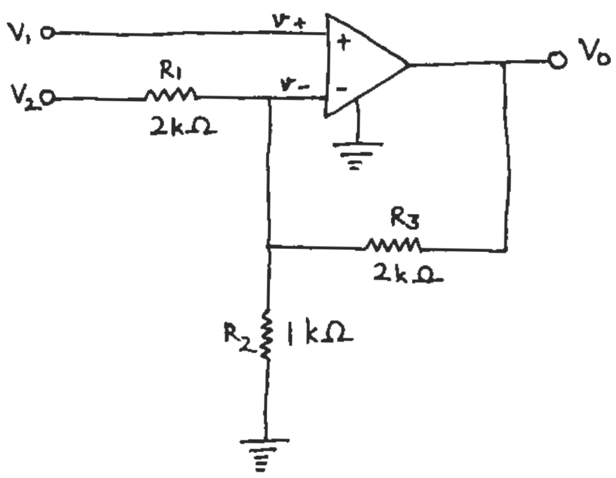


Figure P4.15

Solution: 4·15



$v_+ = v_- = V_1$

KCL at v_- input : $\dfrac{V_2 - V_1}{R_1} = \dfrac{V_1}{R_2} + \dfrac{V_1 - V_0}{R_3}$

$$\Rightarrow V_0 = V_1\left(1 + \frac{R_3}{R_2} + \frac{R_3}{R_1}\right) - V_2\left(\frac{R_3}{R_1}\right)$$

$R_1 = 2\,k\Omega$, $R_2 = 1\,k\Omega$, $R_3 = 2\,k\Omega$, $V_1 = 3\ V$, $V_2 = 9\ V$

$\therefore\ V_0 = 4V_1 - V_2$

$\boxed{V_0 = 3\ V}$

4.16 Find V_o in the circuit in Fig. P4.16 assuming the op-amp is ideal.

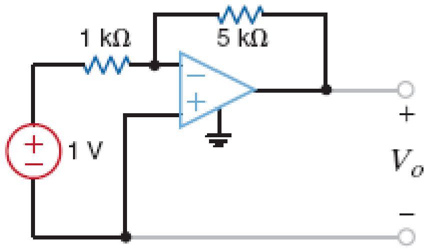
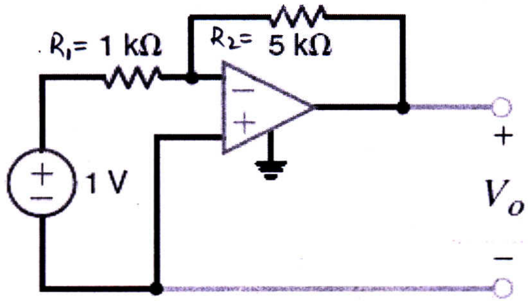


Figure P4.16

SOLUTION:



Inverting op-amp configuration:

$$V_o = \left(\frac{-R_2}{R_1}\right) V_S$$

$$V_o = \left(\frac{-5000}{1000}\right)(1)$$

$$V_o = -5\,V$$

4.17 The network in Fig. P4.17 is a current-to-voltage converter or transconductance amplifier. Find v_o/i_S for this network.

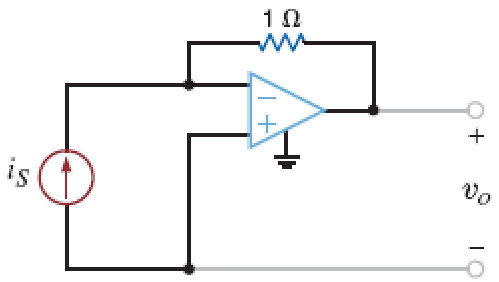
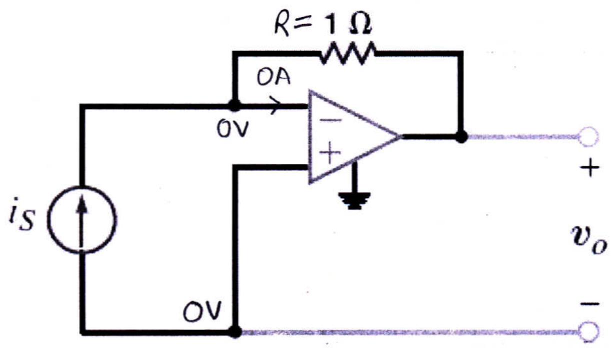


Figure P4.17

SOLUTION:



KCL at V^- : $i_s = 0 + \dfrac{0 - V_o}{R}$

$$i_s = \frac{-V_o}{R}$$

$$\frac{V_o}{i_s} = -R$$

$$\frac{V_o}{i_s} = -1$$

4.18 Calculate the transfer function i_0/v_1 for the network shown in Fig. P4.18.

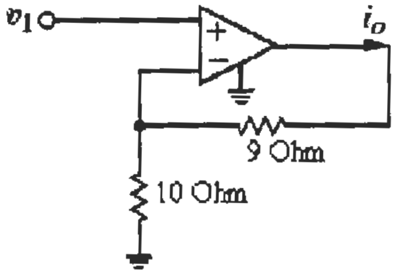
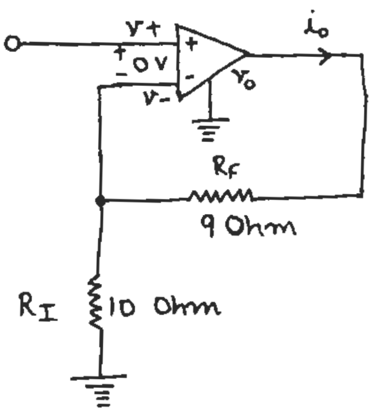


Figure P4.18

Solution: 4.18



$$v_+ = v_- = v_1$$

KCL at v_- input

$$\frac{v_1}{R_I} = \frac{v_o - v_1}{R_F}$$

$$\frac{v_o}{v_1} \quad 1 + \frac{R_F}{R_I} = \frac{R_I + R_F}{R_I}$$

$$v_1 = \frac{v_o}{R_I + R_F} \times R_I$$

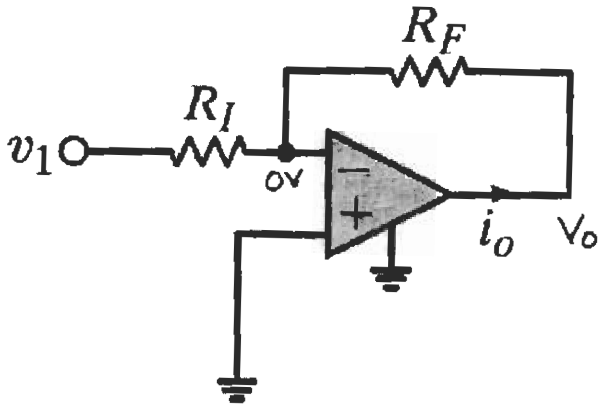
$$\frac{v_o}{R_I + R_F} = \frac{v_1}{R_I}$$

$$i_o = \frac{v_o}{R_I + R_F} = \frac{v_1}{R_I}$$

$\therefore$ Transfer function $\dfrac{i_o}{v_1} = \dfrac{1}{R_I}$

$$\boxed{\frac{i_o}{v_1} = 0.100\ S}$$

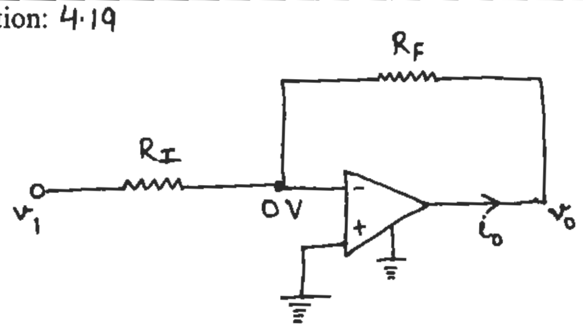
4.19 Determine the relationship between v_I and i_0 in the circuit shown in Fig. P4.19. Find i_0/v_I.



$R_I = 8\Omega$
$R_F = 6\Omega$

Figure P4.19

Solution: 4.19



Basic inverting configuration :

$$\frac{v_o}{v_1} = -\frac{R_F}{R_I}$$

$$i_o = \frac{v_o}{R_F} = \frac{-v_1}{R_I}$$

$$\frac{i_o}{v_1} = -\frac{1}{R_I}$$

$$R_I = 8\Omega \, , \quad \frac{i_o}{v_1} = -\frac{1}{8}$$

$$\boxed{\frac{i_o}{v_1} = -0.125 \text{ S}}$$

4.20 Find V_0 in the network in Fig. P4.20.

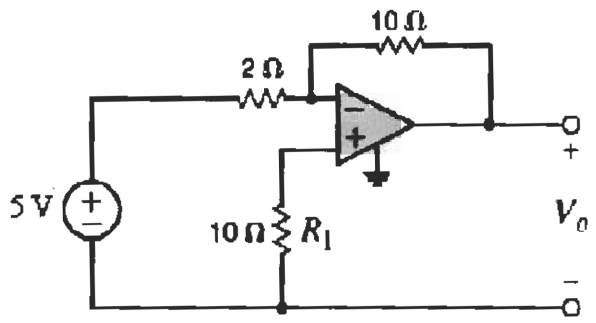
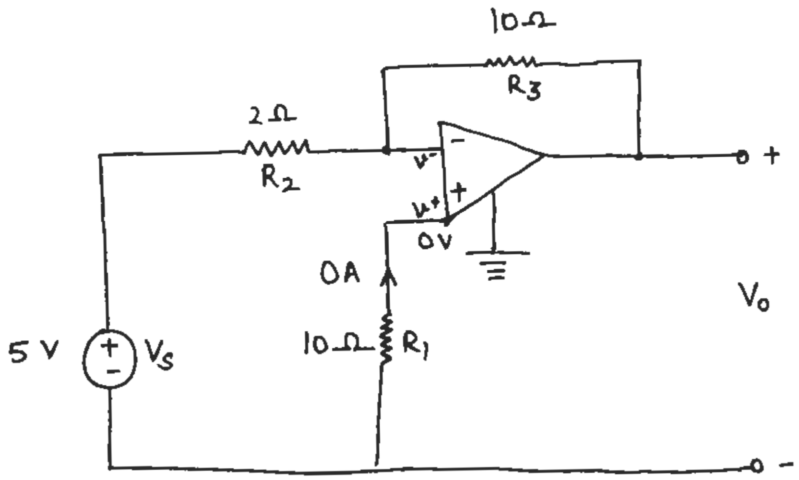


Figure P4.20

Solution: 4.20



$I_{in} = 0$, $v_+ = 0$ for ideal op-amp.

$\therefore$ Voltage across R_1 is 0.

Result is a basic inverting configuration.

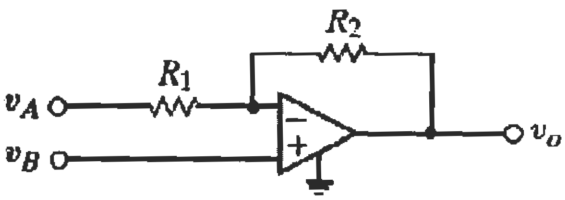
$$\frac{V_o}{V_s} = \frac{-R_3}{R_2}$$

$$\Rightarrow V_o = -5\left(\frac{10}{2}\right)$$

$$= -25 \text{ V}$$

$$\boxed{V_o = -25 \text{ V}}$$

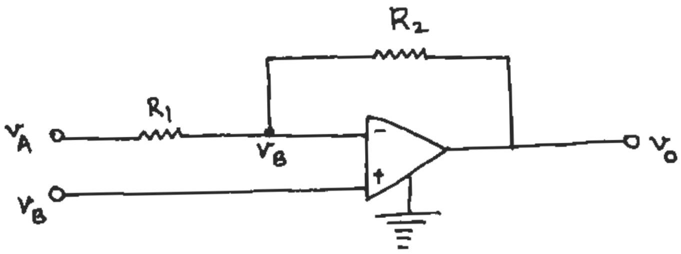
4.21 Determine the value of v_0 in the network in Fig. P4.21.



$R_1 = 14\ \Omega$
$R_2 = 11\ \Omega$
$v_A = 2\ V$
$v_B = 5\ V$

Figure P4.21

Solution: 4.21



KCL at v_- node

$$\frac{V_A - V_B}{R_1} + \frac{V_o - V_B}{R_2} = 0$$

$$\frac{2-5}{14} + \frac{V_o - 5}{11} = 0$$

$$\boxed{V_o = 7.36\ V}$$

4.22 Show that the output of the circuit in Fig. P4.22 is

$$V_0 = \left[1+\frac{R_2}{R_1}\right]V_1 - kV_2$$

Find k, if $R_1 = 5\ \Omega$, $R_2 = 46\ \Omega$, $R_3 = 6\ \Omega$, $R_4 = 12\ \Omega$.

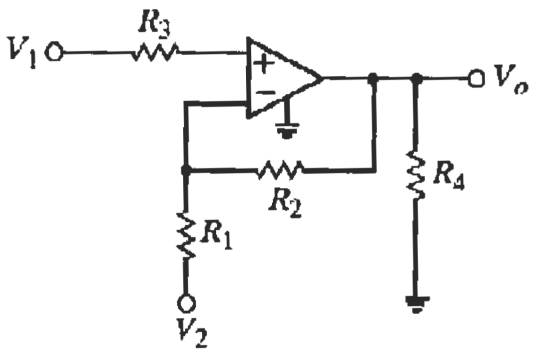
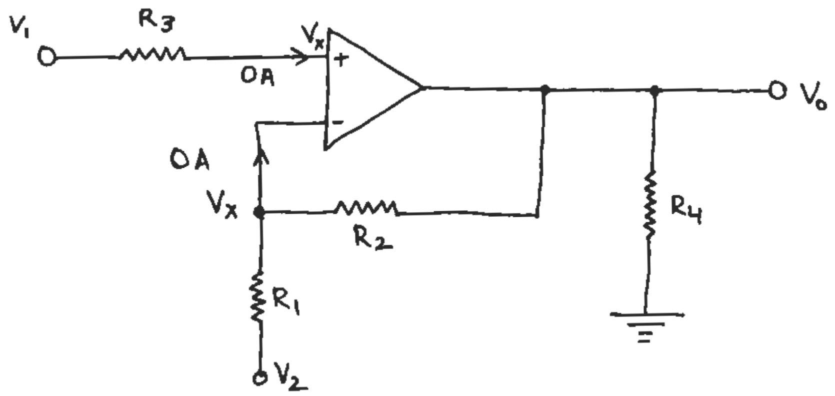


Figure P4.22

Solution: 4.22



KCL at v_+ input: $\dfrac{V_1 - V_x}{R_3} = 0 \Rightarrow V_1 = V_x$

KCL at v_- input: $\dfrac{V_2 - V_x}{R_1} + \dfrac{V_0 - V_x}{R_2} = 0$

$$V_0 = V_x\left(1 + \frac{R_2}{R_1}\right) - V_2\left(\frac{R_2}{R_1}\right)$$

$$\therefore\ V_0 = \left[1 + \frac{R_2}{R_1}\right]V_1 - KV_2\text{, where } K = \frac{R_2}{R_1}$$

$$K = \frac{R_2}{R_1} = 9.2$$

$$\boxed{K = 9.2}$$

4.23 Find V_o in the network in Fig. P4.23.

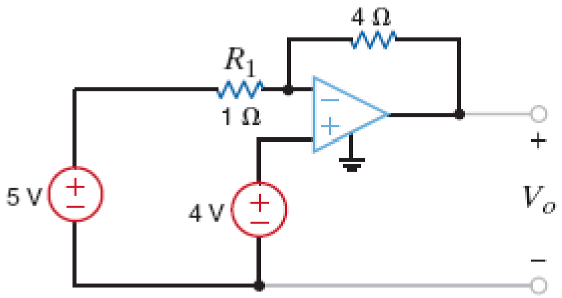
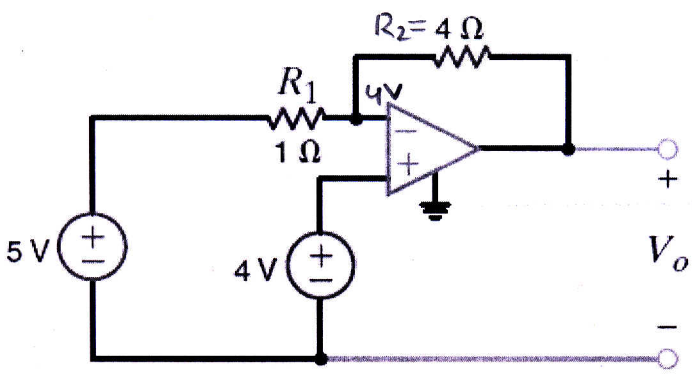


Figure P4.23

SOLUTION:



KCL at V_- : $\dfrac{5-4}{R_1} = \dfrac{4-V_o}{R_2}$

$$V_o = 4 - \frac{R_2}{R_1}(1)$$

$$V_o = 4 - \frac{4}{1}(1)$$

$$V_o = 0V$$

4.24 Find the voltage gain of the op-amp circuit shown in Fig. P4.24.

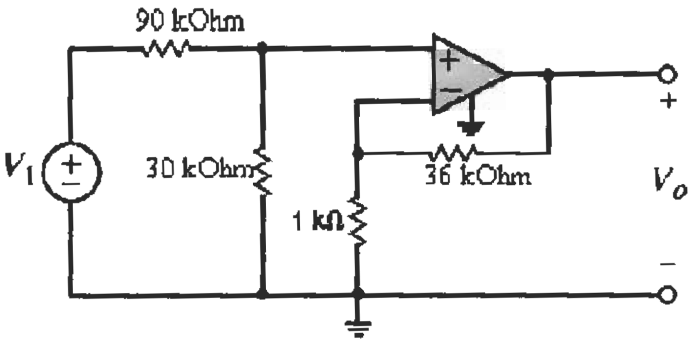
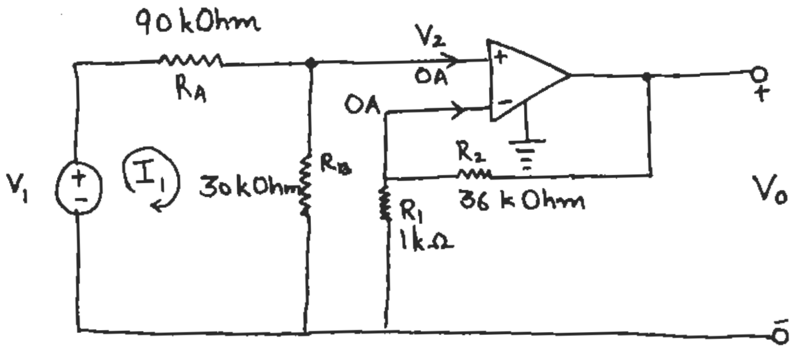


Figure P4.24

Solution: 4.24



Two step solution : 1) Find V_2/V_1
2) Find V_o/V_2

1) Loop analysis : $V_1 = I_1 R_A + I_1 R_B$

$V_2 = I_1 R_B \Rightarrow I_1 = V_2/R_B$

$\frac{V_2}{V_1} = \frac{R_B}{R_A + R_B} = 0.25 \qquad \frac{V_2}{V_1} = 0.25$

2) Op-amp is in basic non-inverting configuration

$\frac{V_o}{V_2} = 1 + \frac{R_2}{R_1} = 37$

Overall gain is $A = \frac{V_o}{V_1} = \left(\frac{V_2}{V_1}\right)\left(\frac{V_o}{V_2}\right)$

$\boxed{A = 9.25}$

4.25 For the circuit in Fig. P4.25 find the value of R_1 that produces a voltage gain of 10.

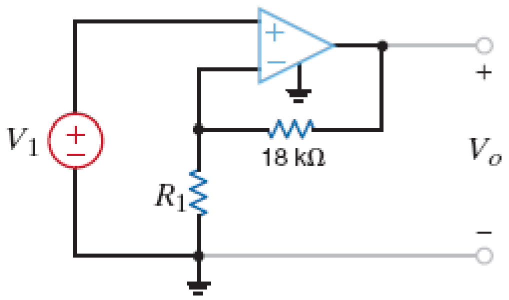
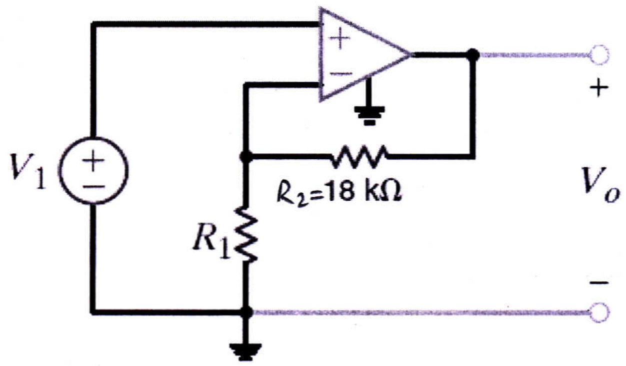


Figure P4.25

SOLUTION:



Non- inverting op-amp:

$$\frac{V_o}{V_1} = 1 + \frac{R_2}{R_1}$$

$$10 = 1 + \frac{18 \times 10^3}{R_1}$$

$$R_1 = 2\,k\Omega$$

4.26 Determine the relationship between v_o and v_{in} in the circuit in Fig. P4.26.

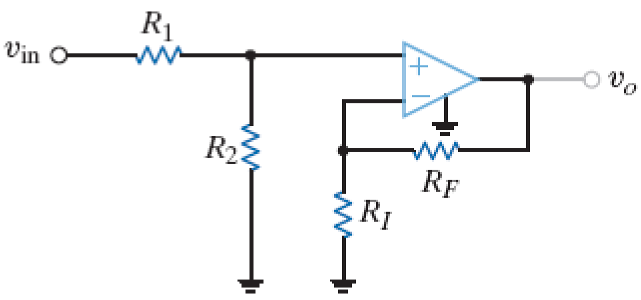
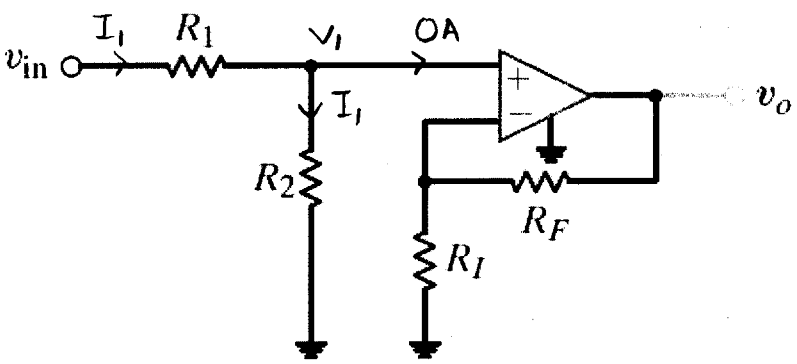


Figure P4.26

SOLUTION:



KVL : $V_{in} = I_1 R_1 + I_1 R_2$

$$V_1 = I_1 R_2$$

$$I_1 = \frac{V_1}{R_2}$$

$$V_{in} = \left(\frac{V_1}{R_2}\right)(R_1) + \left(\frac{V_1}{R_2}\right) R_2$$

$$V_{in} = V_1 + \frac{R_1}{R_2} V_1$$

$$\frac{V_1}{V_{in}} = \frac{R_2}{R_1 + R_2}$$

Non-inverting op-amp:

$$\frac{V_O}{V_1} = 1 + \frac{R_F}{R_I}$$

Overall gain:

$$\frac{V_O}{V_{in}} = \left(\frac{V_O}{V_1}\right)\left(\frac{V_1}{V_{in}}\right)$$

$$\frac{V_O}{V_{in}} = \left(1 + \frac{R_F}{R_I}\right)\left(\frac{R_2}{R_1 + R_2}\right)$$

$$\frac{V_O}{V_{in}} = \left(\frac{R_I + R_F}{R_I}\right)\left(\frac{R_2}{R_1 + R_2}\right)$$

4.27 In the network in the Fig. P4.27 determine the value of V_0.

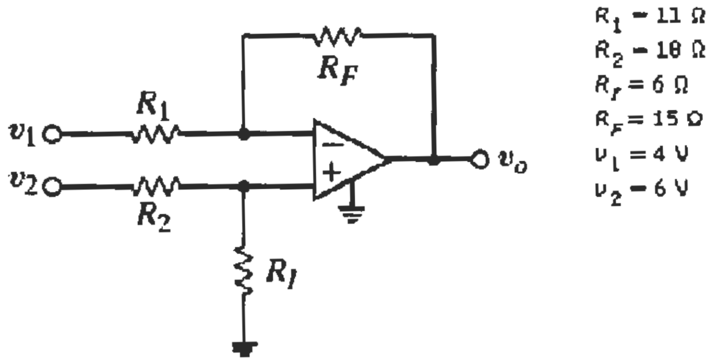
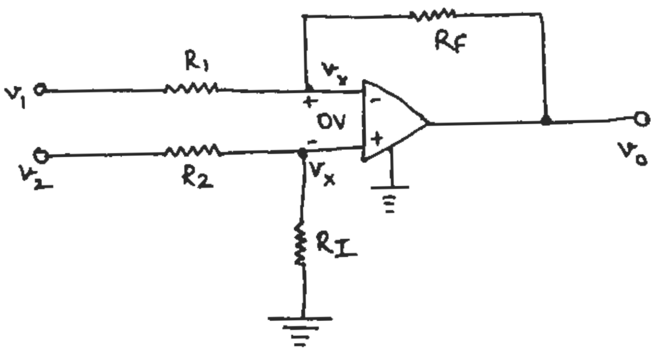


Figure P4.27

Solution: 4.27



KCL at v_+ input : $\dfrac{v_2 - v_x}{R_2} = \dfrac{v_x}{R_I} \Rightarrow v_x = \dfrac{R_I}{R_I + R_2} v_2$ —— ①

KCL at v_- input : $\dfrac{v_1 - v_x}{R_1} = \dfrac{v_x - v_o}{R_F}$

$$\Rightarrow v_o = v_x\left(1 + \frac{R_F}{R_1}\right) - \frac{R_F}{R_1} v_1 \quad \text{—— ②}$$

Substituting the value of v_x from equation ① in ②, we get

$$v_o = v_2\left(\frac{R_I}{R_I + R_2}\right)\left(\frac{R_1 + R_F}{R_1}\right) - \frac{R_F}{R_1} v_1$$

$$\boxed{V_o = -1.91 \text{ V}}$$

4.28 Find V_o in the circuit in Fig. P4.28.

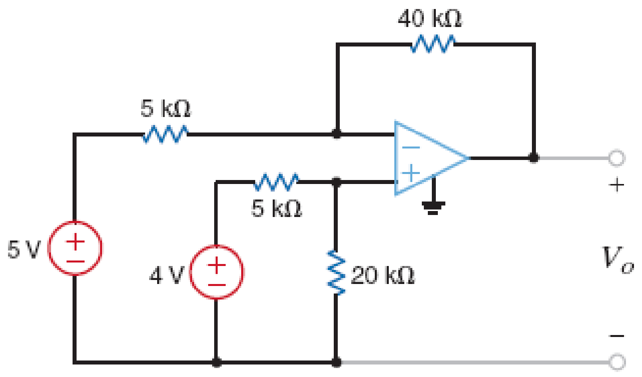
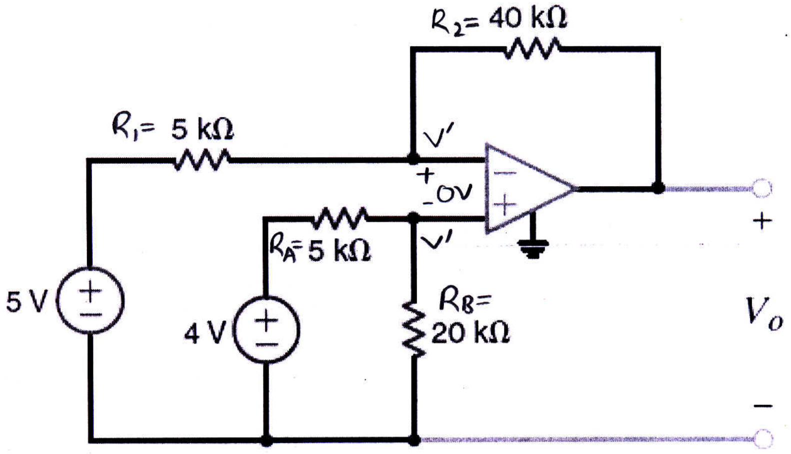


Figure P4.28

SOLUTION:



KCL at V_- :

$$\frac{5-V'}{R_1} = \frac{V'-V_o}{R_2}$$

$$\frac{V'}{R_2} + \frac{V'}{R_1} = \frac{5}{R_1} + \frac{V_o}{R_2}$$

$$V'\left(\frac{R_1+R_2}{R_1R_2}\right) = \frac{5R_2 + R_1V_o}{R_1R_2}$$

$$V' = 5\left(\frac{R_2}{R_1+R_2}\right) + V_o\left(\frac{R_1}{R_1+R_2}\right)$$

KCL at V_+ : $\dfrac{4-V'}{R_A} = \dfrac{V'}{R_B}$

$$V' = \frac{4R_B}{R_A + R_B}$$

$$5\left(\frac{R_2}{R_1+R_2}\right) + V_0\left(\frac{R_1}{R_1+R_2}\right) = \frac{4R_B}{R_A+R_B}$$

$$V_0 = \left(\frac{4R_B}{R_A+R_B} - \frac{5R_2}{R_1+R_2}\right)\left(\frac{R_1+R_2}{R_1}\right)$$

$$V_0 = -11.2\,V$$

4.29 Find V_o in the circuit in Fig. P4.29.

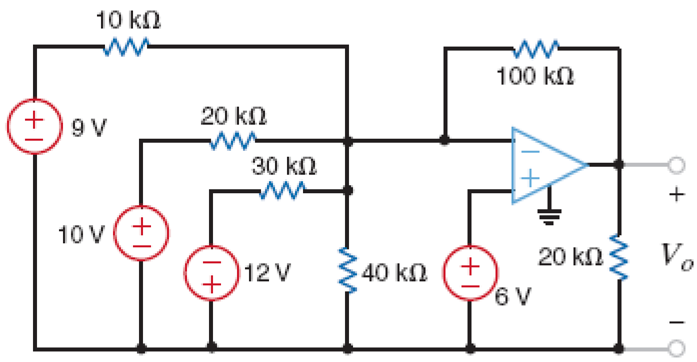
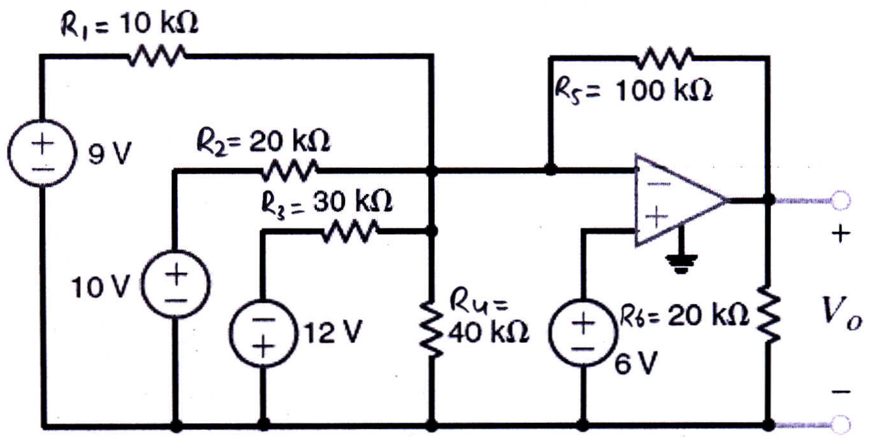


Figure P4.29

SOLUTION:



KCL at V_- : $\dfrac{9-6}{R_1} + \dfrac{10-6}{R_2} + \dfrac{-12-6}{R_3} = \dfrac{6}{R_4} + \dfrac{6-V_o}{R_5}$

$$\frac{3}{R_1} + \frac{4}{R_2} - \frac{18}{R_3} - \frac{6}{R_4} - \frac{6}{R_5} = -\frac{V_o}{R_5}$$

$$V_o = 31\text{V}$$

4.30 Determine the value of the output voltage, v_0, of the inverting summer circuit in the Fig. P4.30.

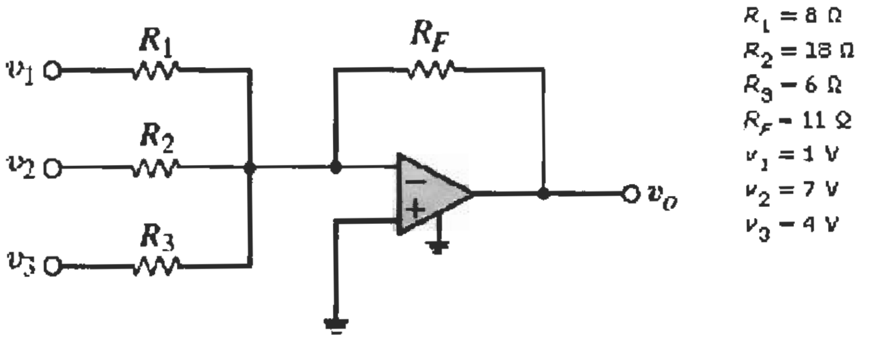
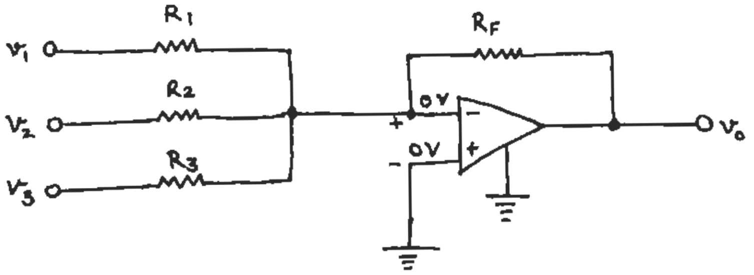


Figure P4.30

Solution: 4.30



KCL at v_- input: $\dfrac{v_1 - 0}{R_1} + \dfrac{v_2 - 0}{R_2} + \dfrac{v_3 - 0}{R_3} = \dfrac{0 - v_o}{R_F}$

$$v_o = -\frac{R_F}{R_1} v_1 - \frac{R_F}{R_2} v_2 - \frac{R_F}{R_3} v_3$$

$$\Rightarrow \boxed{v_o = -13.0\ \text{V}}$$

4.31 Determine the value of the output voltage, V_0, of the noninverting averaging circuit shown in the Fig. P4.31.

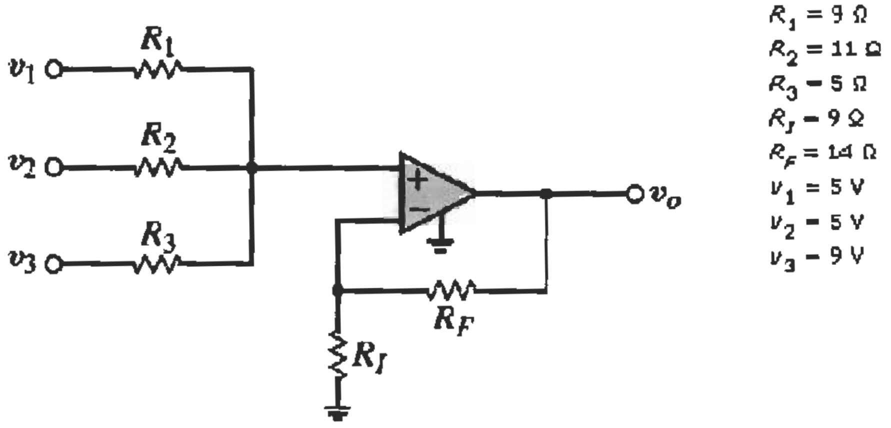
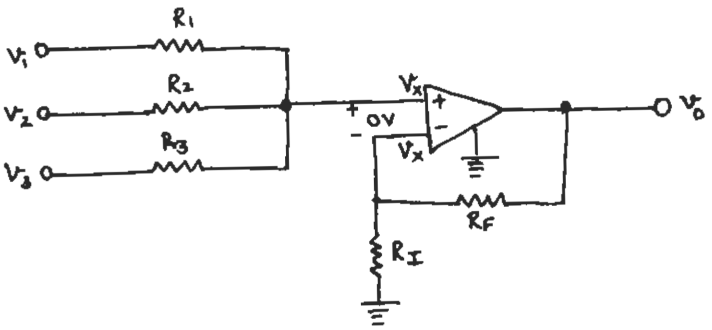


Figure P4.31

Solution: 4.31



KCL at V_+ input $= \dfrac{V_1 - V_x}{R_1} + \dfrac{V_2 - V_x}{R_2} + \dfrac{V_3 - V_x}{R_3} = 0$ — ①

KCL at V_- input $= \dfrac{V_0 - V_x}{R_F} = \dfrac{V_x}{R_I} \Rightarrow V_x = V_0\left(\dfrac{R_I}{R_I + R_F}\right)$ — ②

Substituting equation ② in ①, we get

$$V_0 = \left(\frac{R_I + R_F}{R_I}\right)\left[\frac{R_2 R_3 V_1 + R_1 R_3 V_2 + R_1 R_2 V_3}{R_1 R_2 + R_2 R_3 + R_1 R_3}\right]$$

$\Rightarrow V_0 = 17.863$ V

$$\boxed{V_0 = 17.9 \text{ V}}$$

4.32 Find the input/output relationship for the current amplifier shown in Fig. P4.32.

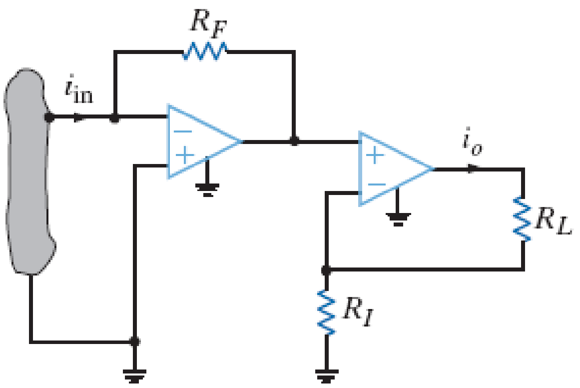
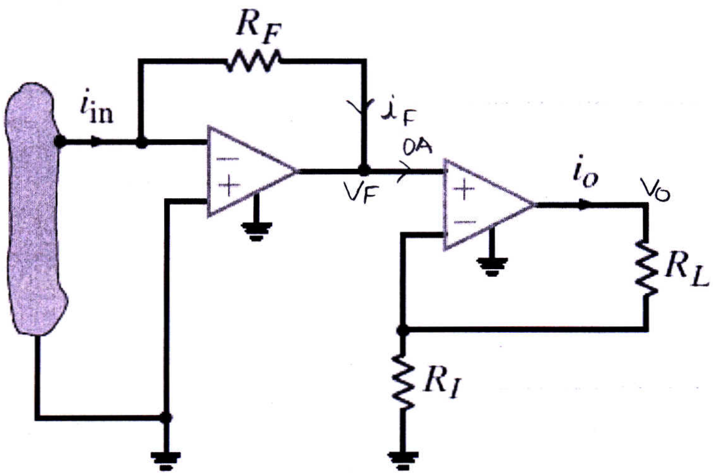


Figure P4.32

SOLUTION:



KCL at V_- of the op-amp on the left side :

$$i_{in} = \frac{0 - V_F}{R_F}$$

$$V_F = -i_{in}R_F$$

op-amp on the right is a non-inverting op-amp :

$$V_o = \left(1 + \frac{R_L}{R_I}\right)V_F$$

$$i_o = \frac{V_o - V_F}{R_L}$$

$$i_o = \frac{V_F\left(\frac{R_I + R_L}{R_I}\right) - V_F}{R_L}$$

$$i_o = \frac{V_F\left(\frac{R_I + R_L - R_I}{R_I}\right)}{R_L}$$

$$i_o = \frac{V_F}{R_I}$$

$$\frac{i_o}{i_{in}} = \left(\frac{V_F}{i_{in}}\right)\left(\frac{i_o}{V_F}\right)$$

$$\frac{i_o}{i_{in}} = \left(\frac{-i_{in} R_F}{i_{in}}\right)\left(\frac{\frac{V_F}{R_I}}{V_F}\right)$$

$$\frac{i_o}{i_{in}} = \frac{-R_F}{R_I}$$

4.33 Find V_o in the circuit in Fig. P4.33.

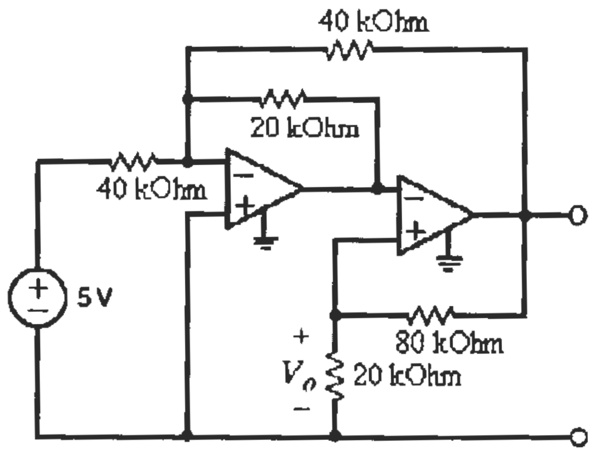
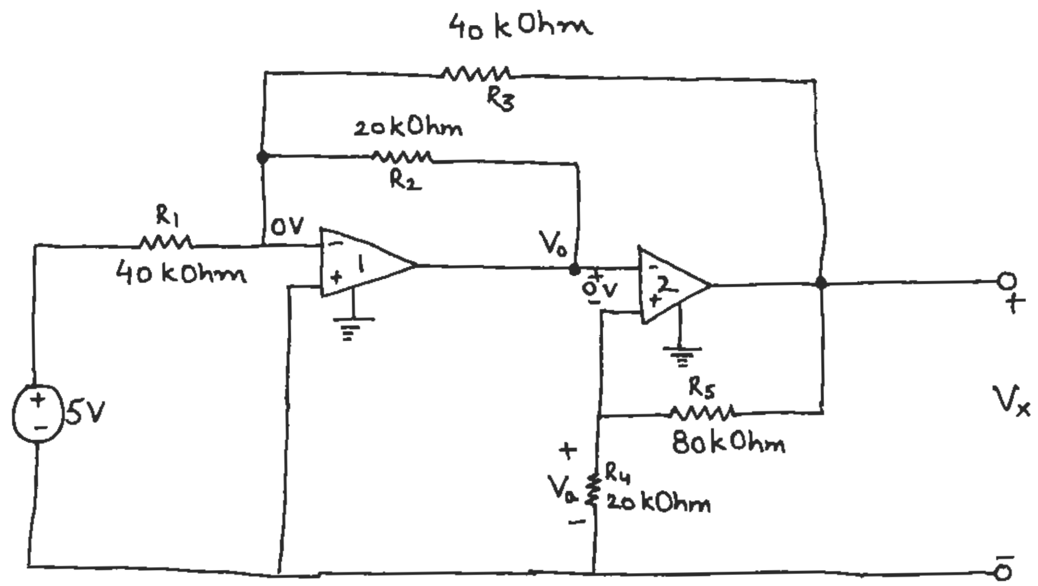


Figure P4.33

Solution: 4.33



KCL at v_- input of 1st op-amp: $\frac{5}{R_1} + \frac{V_o}{R_2} + \frac{V_x}{R_3} = 0$

$$\Rightarrow V_x = \frac{-R_3}{R_1}(5) - \frac{R_3}{R_2} V_o \quad \text{—— (1)}$$

KCL at v_+ input of 2nd op-amp: $\frac{V_o}{R_4} + \frac{V_o - V_x}{R_5} = 0$

$$\Rightarrow V_x = V_o\left(1 + \frac{R_5}{R_4}\right) \quad \text{—— (2)}$$

From (2) $V_x = 5V_o$

Substituting $V_x = 5V_o$ in equation (1), we get

$\boxed{V_o = -0.714\ V}$

4.34 Find v_o in the circuit in Fig. P4.34.

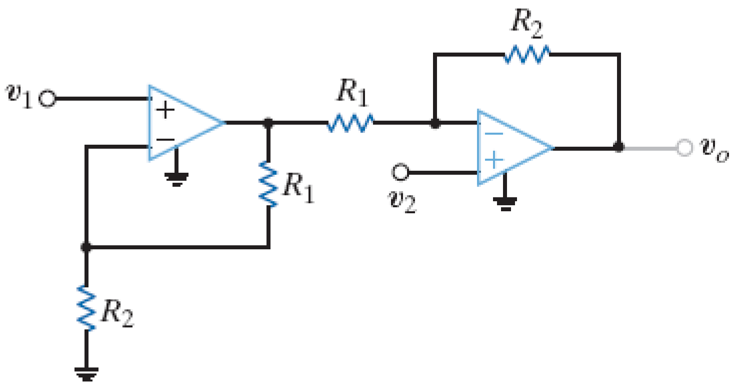
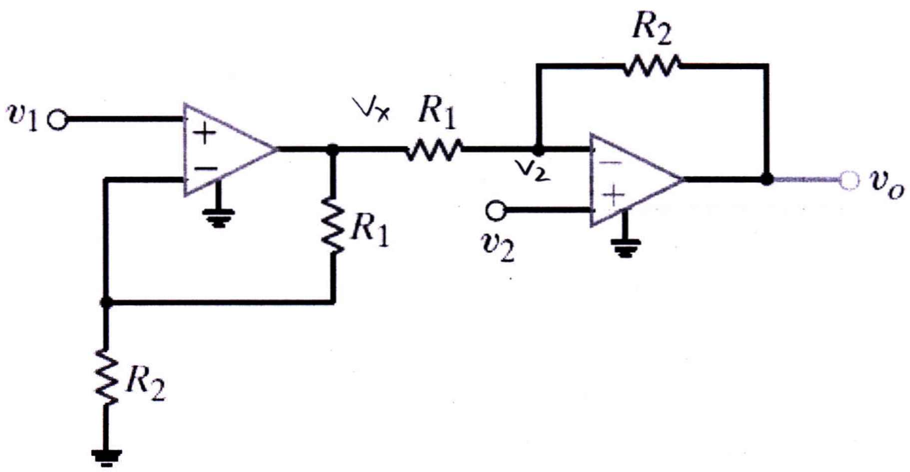


Figure P4.34

SOLUTION:



The first op-amp is a non-inverting configuration.

$$\frac{V_x}{V_1} = 1 + \frac{R_1}{R_2}$$

$$V_x = V_1 \left(\frac{R_2 + R_1}{R_2} \right)$$

KCL at V_- of the 2nd op-amp:

$$\frac{V_x - V_2}{R_1} + \frac{V_0 - V_2}{R_2} = 0$$

$$V_0 = V_2\left(1 + \frac{R_2}{R_1}\right) - \frac{R_2}{R_1} V_x$$

$$V_0 = V_2\left(1 + \frac{R_2}{R_1}\right) - \frac{R_2}{R_1}\left(V_1\left[\frac{R_2 + R_1}{R_2}\right]\right)$$

$$V_0 = \left(1 + \frac{R_2}{R_1}\right)(V_2 - V_1)$$

4.35 Determine the value of V_0 in the differential amplifier circuit shown in the Fig. P4.35.

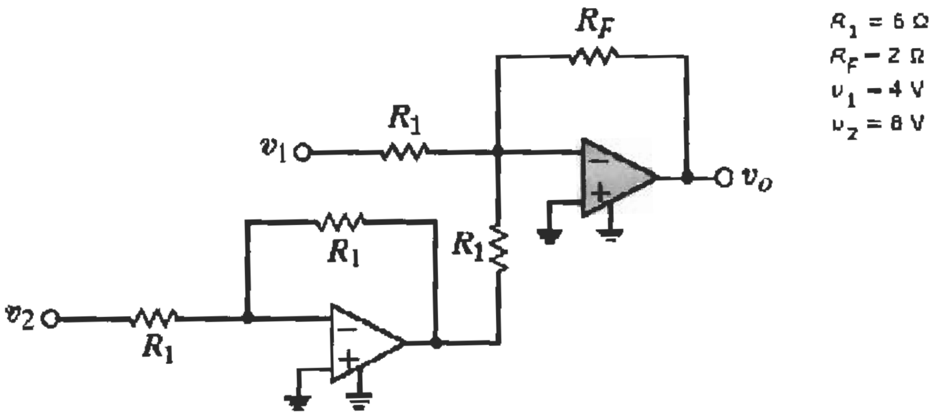
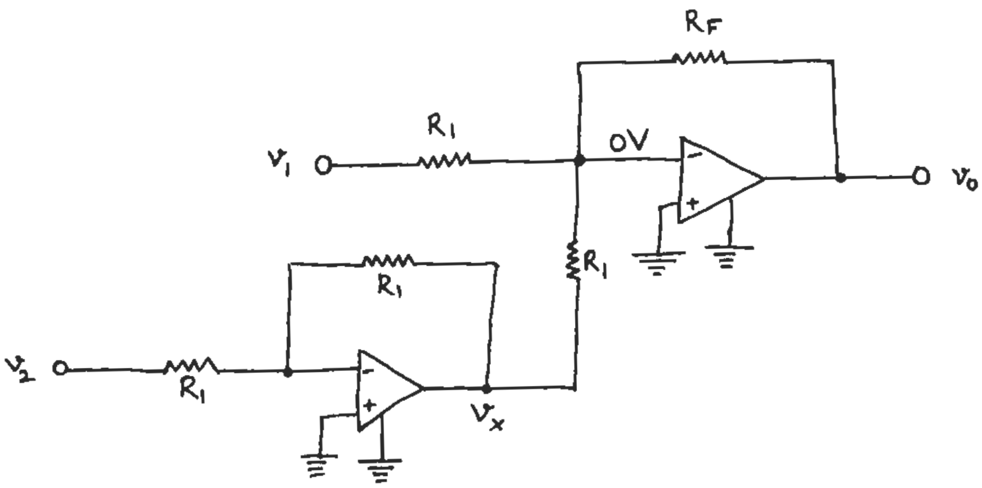


Figure P4.35

Solution: 4.35



1st op-amp is in inverting configuration:

$$V_x = -\frac{R_1}{R_1} V_2 \Rightarrow V_x = -V_2 \quad \text{—— (1)}$$

KCL at V_- input of 2nd op-amp : $\frac{V_1}{R_1} + \frac{V_x}{R_1} + \frac{V_0}{R_F} = 0$ —— (2)

Substituting equation (1) in (2) we get

$$V_0 = \frac{R_F}{R_1}(V_2 - V_1)$$

$$\boxed{V_0 = 1.33\ \text{V}}$$

4.36 Find v_o in the circuit in Fig. P4.36.

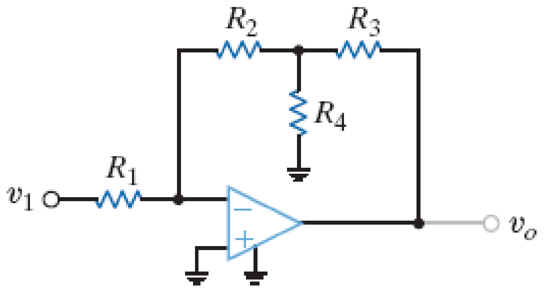
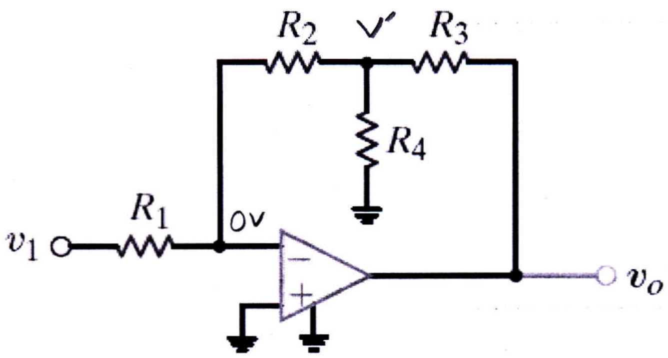


Figure P4.36

SOLUTION:



KCL at V_- : $\dfrac{V_1}{R_1} + \dfrac{V'}{R_2} = 0$

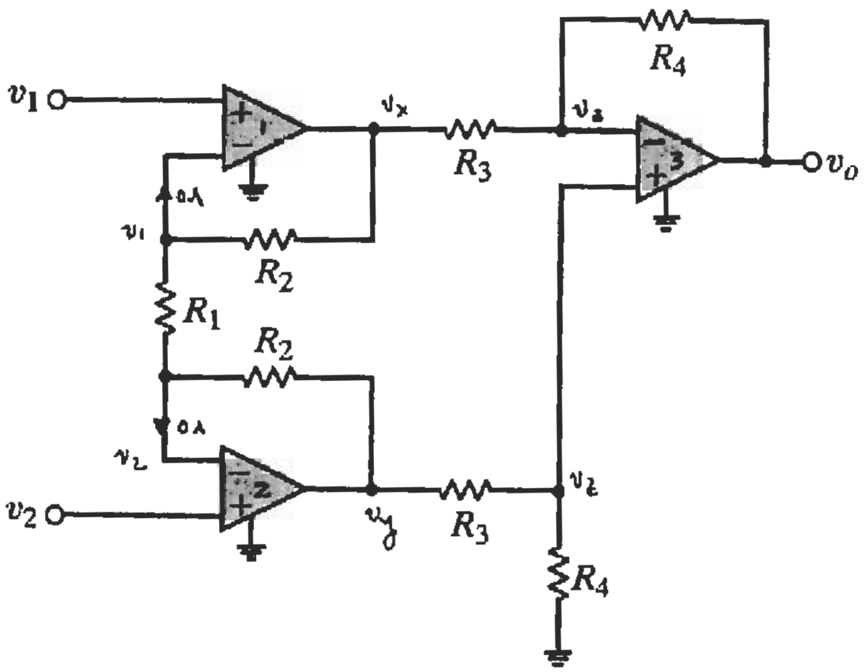
$$V' = -\frac{R_2}{R_1} V_1$$

KCL at V' : $\dfrac{V'}{R_2} + \dfrac{V'}{R_4} + \dfrac{V' - V_o}{R_3} = 0$

$$V_o = \left(\frac{R_3}{R_2} + \frac{R_3}{R_4} + 1 \right) V'$$

$$V_o = \left(\frac{R_3}{R_2} + \frac{R_3}{R_4} + 1 \right) \left(\frac{-R_2}{R_1} \right) V_1$$

4.37 Find the output voltage, V_0, in the circuit in Fig. P4.37.



$R_1 = 2\Omega$
$R_2 = 6\Omega$
$R3 = 2\Omega$
$R_4 = 6\Omega$
$V_1 = 6$ V
$V_2 = 8$ V

Figure P4.37

Solution: 4.37

KCL at v_- of op-amp 1: $\dfrac{v_x - v_1}{R_2} = \dfrac{v_1 - v_2}{R_1}$

$$\Rightarrow v_x = v_1\left(1 + \frac{R_2}{R_1}\right) - \frac{R_2}{R_1} v_2 \quad \text{—— (1)}$$

KCL at v_- of op-amp 2: $\dfrac{v_y - v_2}{R_2} = \dfrac{v_2 - v_1}{R_1}$

$$\Rightarrow v_y = v_2\left(1 + \frac{R_2}{R_1}\right) - \frac{R_2}{R_1} v_1 \quad \text{—— (2)}$$

KCL at v_+ of op-amp 3: $\dfrac{v_y - v_z}{R_3} = \dfrac{v_z}{R_4}$

$$\Rightarrow v_z = v_y\left(\frac{R_4}{R_3 + R_4}\right) \quad \text{—— (3)}$$

KCL at v_- of op-amp 3: $\dfrac{v_x - v_z}{R_3} + \dfrac{v_0 - v_z}{R_4} = 0$

$$\Rightarrow v_0 = v_z\left(1 + \frac{R_4}{R_3}\right) - \frac{R_4}{R_3} v_x \quad \text{—— (4)}$$

From 1, we get, $v_x = 0$

From 2, we get, $v_y = 14$ V

Substituting the value of v_y in equation 3, we get

$$v_z = \frac{21}{2} \text{ V}$$

Substituting the values of v_z and v_x in equation 4, we get

$$\boxed{V_o = 42 \text{ V}}$$

4.38 The electronic ammeter in Example 4.9 has been modified and is shown in Fig. P4.38. The selector switch allows the user to change the range of the meter. Using values for R_1 and R_2 from Example 4.9, find the values of R_A and R_B that will yield a 10-V output when the current being measured is 100 mA and 10 mA, respectively.

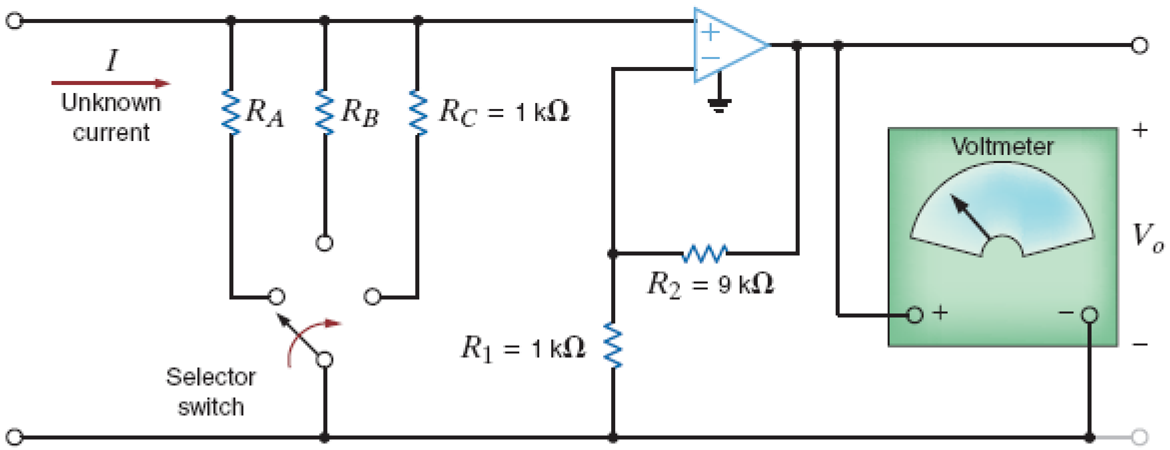
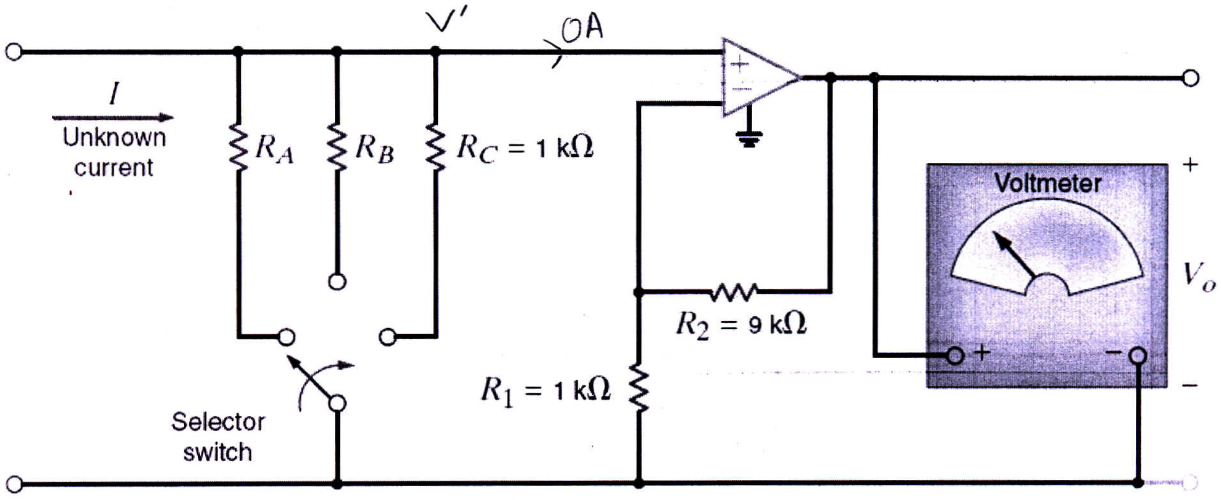


Figure P4.38

SOLUTION:



Non-inverting op-amp:

$$V_o = \left(1 + \frac{R_2}{R_1}\right) V' = 10V'$$

$$V' = IR_A = 0.1 R_A$$

$$V_o = 10V'$$

$$V_0 = 10(0.1R_A) = 10$$

$$R_A = 10\Omega$$

$$V' = IR_B = 0.01R_B$$

$$V_0 = 10V' = 10(0.01R_B) = \frac{R_B}{10}$$

$$\frac{R_B}{10} = 10$$

$$R_B = 100\,\Omega$$

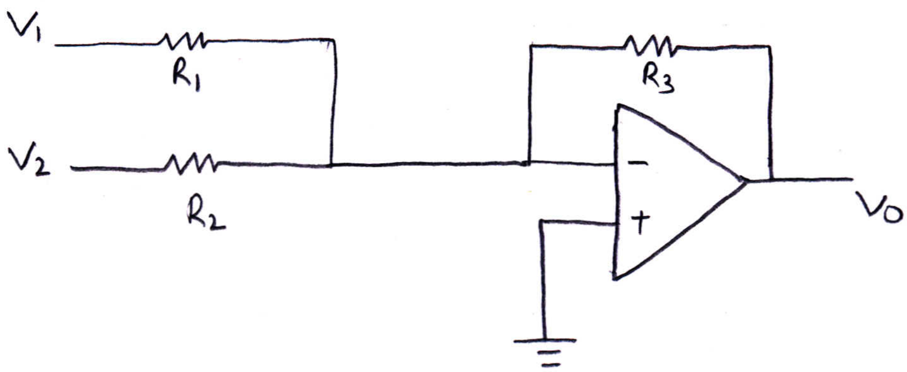
4.39 Given a box of 10-kΩ resistors and an op-amp, design a circuit that will have an output voltage of

$$V_o = -2V_1 - 4V_2$$

SOLUTION:

$$V_O = -2V_1 - 4V_2$$

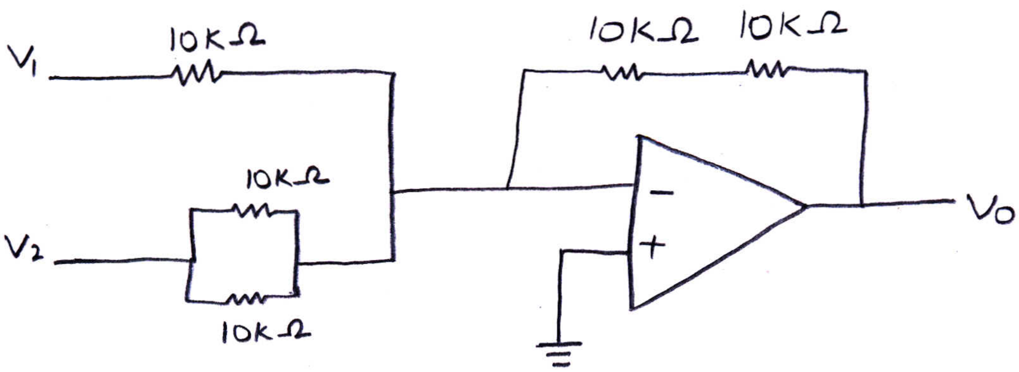
A summer will produce the output given:



$$V_O = -\frac{R_3}{R_1} V_1 - \frac{R_3}{R_2} V_2$$

$$V_O = -2V_1 - 4V_2$$

The following circuit will work:



4.40 Design an op-amp circuit that has a gain of −110 using resistors no smaller than 1kΩ. The circuit is given

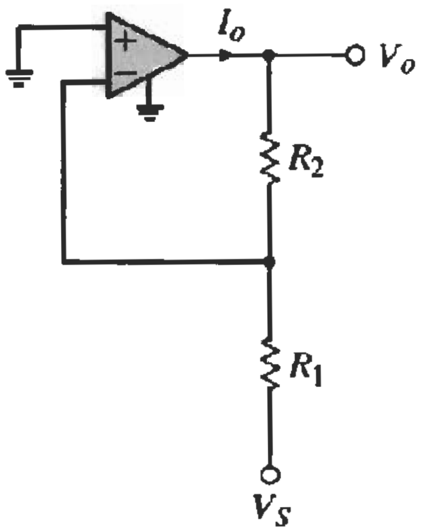
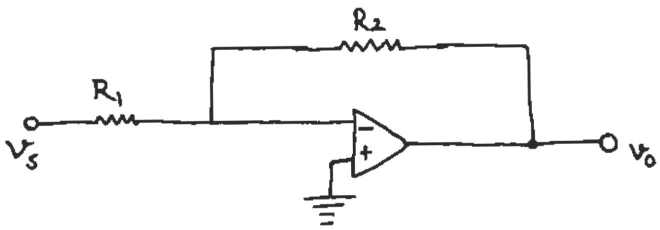


Figure P4.40

If $R_1 = 3$ kΩ, Find R_2.

Solution: 4.40



Since the gain is negative, use inverting configuration:

$$\frac{V_o}{V_s} = -\frac{R_2}{R_1} = -110$$

$$\frac{R_2}{R_1} = 110$$

Choose $R_1 = 5\,k\Omega$, then $R_2 = 550\,k\Omega$

If $R_1 = 3\,k\Omega$,

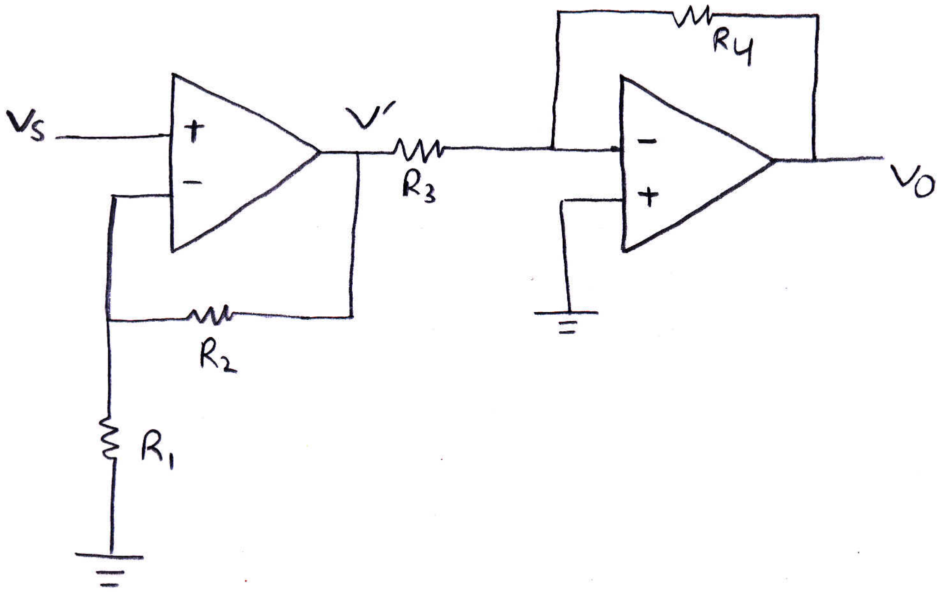
$$\boxed{R_2 = 330\,k\Omega}$$

4.41 Design a two-stage op-amp network that has a gain of −50,000 while drawing no current into its input terminal. Use no resistors smaller than 1 kΩ.

SOLUTION:

For no input current, a non-inverting op-amp can be used

For a negative value, an inverting op-amp can be used



$$\frac{V'}{V_S} = 1 + \frac{R_2}{R_1}$$

$$\frac{V_O}{V'} = -\frac{R_4}{R_3}$$

$$\frac{V_O}{V_S} = -\frac{R_4}{R_3}\left(1 + \frac{R_2}{R_1}\right)$$

Select $\frac{V_x}{V_s} = 250$

and $\frac{V_o}{V_x} = -200$

$R_1 = R_3 = 2\,K\Omega$

$250 = 1 + \frac{R_2}{2000}$

$R_2 = 498\,K\Omega$

$-200 = \frac{-R_4}{2000}$

$R_4 = 400\,K\Omega$

4.42 Design an op-amp circuit that has the following input/output relationship: $V_0 = -18V_1 + 0.5\,V_2$. The circuit is given

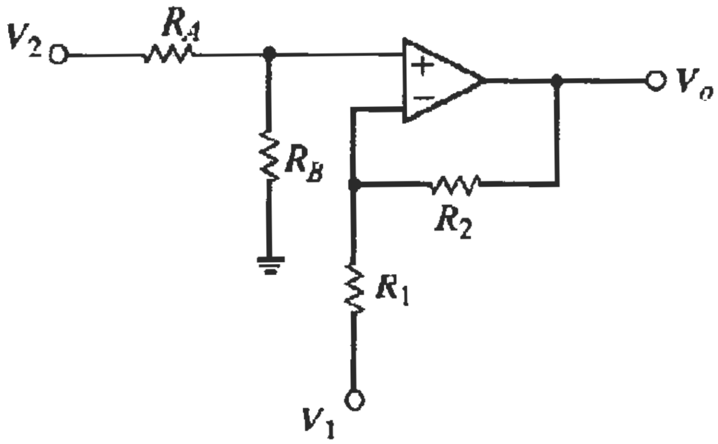
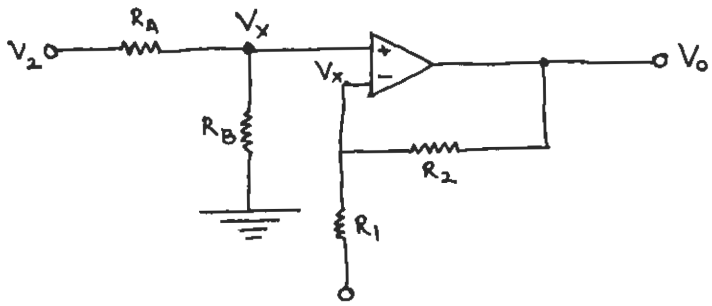


Figure P4.42

If $R_B = 1\text{k}\Omega$ and $R_1 = 1\text{k}\Omega$, Find (a) R_A and (b) R_2.

Solution: 4.42



KCL at V_+ : $\dfrac{V_2 - V_x}{R_A} = \dfrac{V_x}{R_B}$

$$\Rightarrow \quad \frac{V_x}{V_2} = \frac{R_B}{R_A + R_B} \quad \text{———} \quad (1)$$

KCL at V_- : $\dfrac{V_o - V_x}{R_2} = \dfrac{V_x - V_1}{R_1}$

$$\Rightarrow \quad V_o = V_x\left(1 + \frac{R_2}{R_1}\right) - \frac{R_2}{R_1}V_1 \quad \text{———} \quad (2)$$

Substituting equation (1) in (2), we get

$$V_o = -\frac{R_2}{R_1}V_1 + \frac{R_B}{R_A + R_B}\left(1 + \frac{R_2}{R_1}\right)V_2 \quad \text{———} \quad (3)$$

$$= -18\,V_1 + 0.5\,V_2$$

$\therefore \quad \frac{R_2}{R_1} = 18 \quad$ choose $R_1 = 2\text{ k}\Omega$, $R_2 = 36\text{ k}\Omega$

Substituting $\frac{R_2}{R_1} = 18$ in equation (3), we get

$$V_o = -18\,V_1 + \frac{R_B}{R_A + R_B}(1 + 18)\,V_2$$

$$= -18\,V_1 + \frac{19\,R_B}{R_A + R_B}\,V_2$$

$$= -18\,V_1 + 0.5\,V_2$$

Therefore $\quad \frac{19\,R_B}{R_A + R_B} = 0.5$

$\Rightarrow \quad \frac{R_A}{R_B} = 37 \quad$ choose $R_B = 5\text{ k}\Omega$, $R_A = 185\text{ k}\Omega$

Therefore, for the given input/output relationship, we can choose $R_1 = 2\text{ k}\Omega$, $R_2 = 36\text{ k}\Omega$, $R_A = 185\text{ k}\Omega$, $R_B = 5\text{ k}\Omega$

If $R_B = 1\text{ k}\Omega$, $R_1 = 1\text{ k}\Omega$

$\boxed{R_A = 37\text{ k}\Omega}$

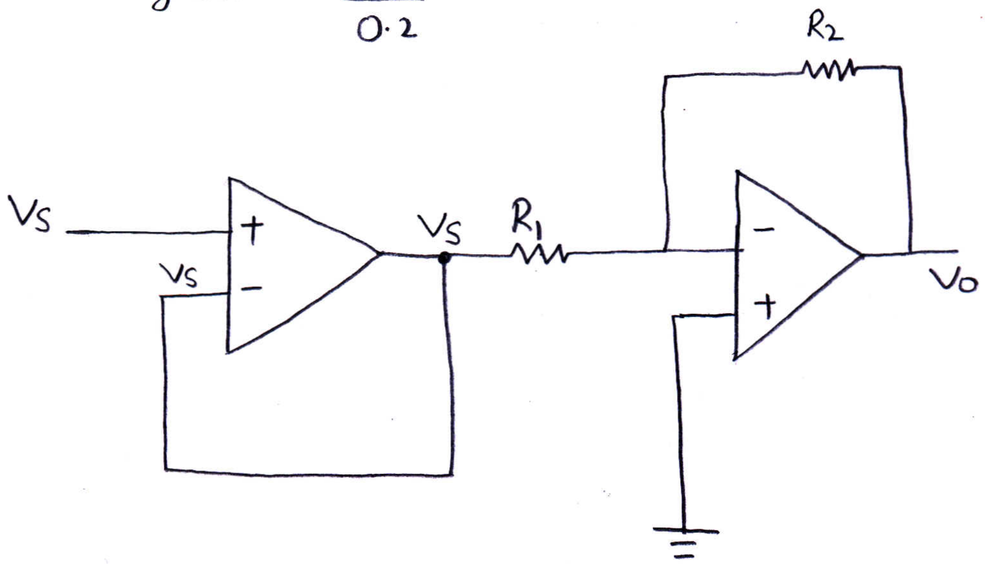
$\boxed{R_2 = 18\text{ k}\Omega}$

4.43 A voltage waveform with a maximum value of 200 mV must be amplified to a maximum of 10 V and inverted. However, the circuit that produces the waveform can provide no more than 100 μA. Design the required amplifier.

SOLUTION:

A non-inverting op-amp followed by an inverting op-amp will work.

$$\text{gain} = \frac{-10}{0.2} = -50$$



$$\frac{V_o}{V_s} = \frac{-R_2}{R_1}$$

Select $R_1 = 1\,K\Omega$

$$R_2 = -50(-1000)$$

$$R_2 = 50\,K\Omega$$

4.44 An amplifier with a gain of $\pi \pm 1\%$ is needed. Design the amplifier. The amplifier is drawn

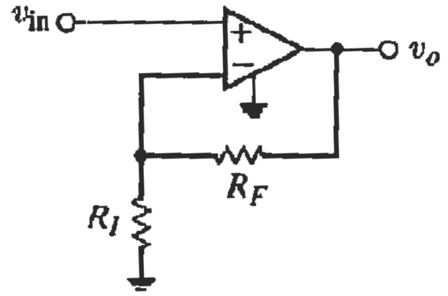
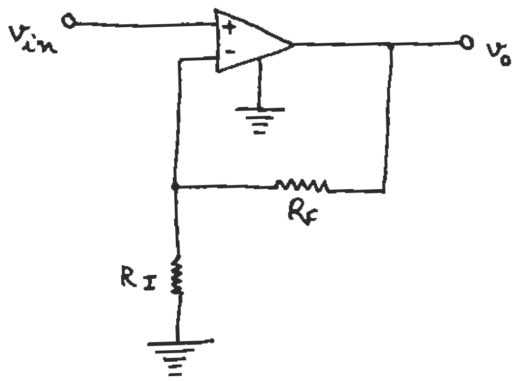


Figure P4.44

If $R_1 = 8\ k\Omega$, Find R_F.

Solution: 4.44



For positive gain, use non-inverting configuration

$$\frac{V_o}{V_{in}} = 1 + \frac{R_2}{R_1} = A$$

For $A = \pi \pm 1\%$, $2.111 \leq \frac{R_F}{R_I} \leq 2.174$

We choose $R_I = 20\ k\Omega$, $R_F = 43\ k\Omega$

$A = 3.15$ and this is within the limit $3.111 < A < 3.174$

If $R_I = 8\ k\Omega$, $1 + \frac{R_F}{R_I} = 3.15$

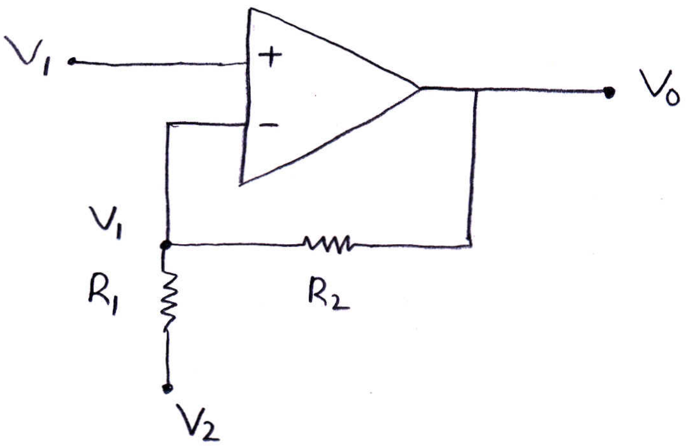
$$\boxed{R_F = 17.2\ k\Omega}$$

4.45 Design an op-amp-based circuit to produce the function

$$V_o = 5\,V_1 - 4\,V_2$$

SOLUTION:

$$V_o = 5V_1 - 4V_2$$



KCL at V_- : $\dfrac{V_o - V_1}{R_2} = \dfrac{V_1 - V_2}{R_1}$

$$V_o = \frac{R_2}{R_1}V_1 + V_1 - \frac{R_2}{R_1}V_2$$

$$V_o = \left(1 + \frac{R_2}{R_1}\right)V_1 - \frac{R_2}{R_1}V_1$$

Select $R_1 = 5K\Omega$

$$R_2 = 20K\Omega$$

4.46 Design an op-amp-based circuit to produce the function

$$V_0 = 5V_1 - 7V_2.$$

The circuit is given

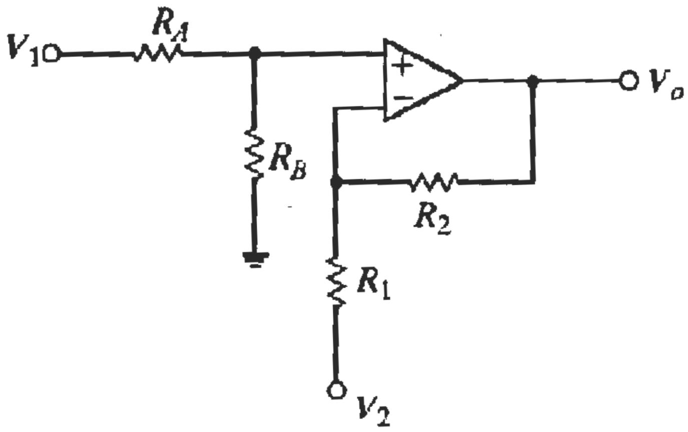
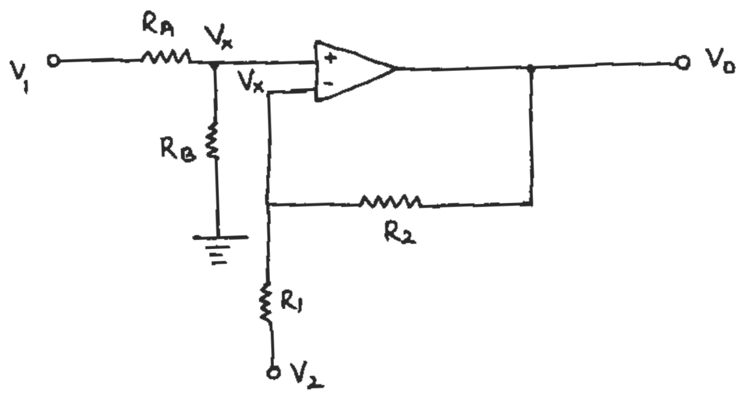


Figure P4.46

If $R_B = 40\ k\Omega$ and $R_1 = 8\ k\Omega$, Find (a) R_A and (b) R_2.

Solution: 4·46



Use both + and - inputs to get + and - gains

KCL at v_+ input: $\dfrac{V_1 - V_x}{R_A} = \dfrac{V_x}{R_B}$

$$\Rightarrow \frac{V_x}{V_1} = \frac{R_B}{R_A + R_B} \quad \text{—— ①}$$

KCL at v_- input: $\dfrac{V_o - V_x}{R_2} = \dfrac{V_x - V_2}{R_1}$

$$\Rightarrow V_o = V_x\left(1 + \frac{R_2}{R_1}\right) - \frac{R_2}{R_1}V_2 \quad \text{—— ②}$$

Substituting V_x from equation ① in ②, we get

$$V_0 = V_1 \left(\frac{R_B}{R_A + R_B}\right)\left(1 + \frac{R_2}{R_1}\right) - \frac{R_2}{R_1} V_2$$

$\frac{R_2}{R_1} = 7$ Choose $R_1 = 1\,k\Omega \Rightarrow R_2 = 7\,k\Omega$

$\left(\frac{R_B}{R_A + R_B}\right) 8 = 5$ Choose $R_B = 5\,k\Omega \Rightarrow R_A = 3\,k\Omega$

If $R_B = 40\,k\Omega$ and $R_1 = 8\,k\Omega$,

$\boxed{R_A = 24\,k\Omega}$, $\boxed{R_2 = 56\,k\Omega}$

4.47 Show that the circuit in Fig. P4.47 can produce the output

$$V_o = K_1 V_1 - K_2 V_2$$

only for $0 \leq K_1 \leq K_2 + 1$.

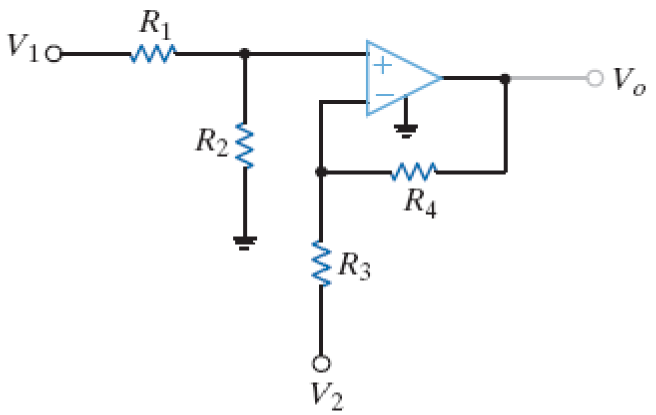
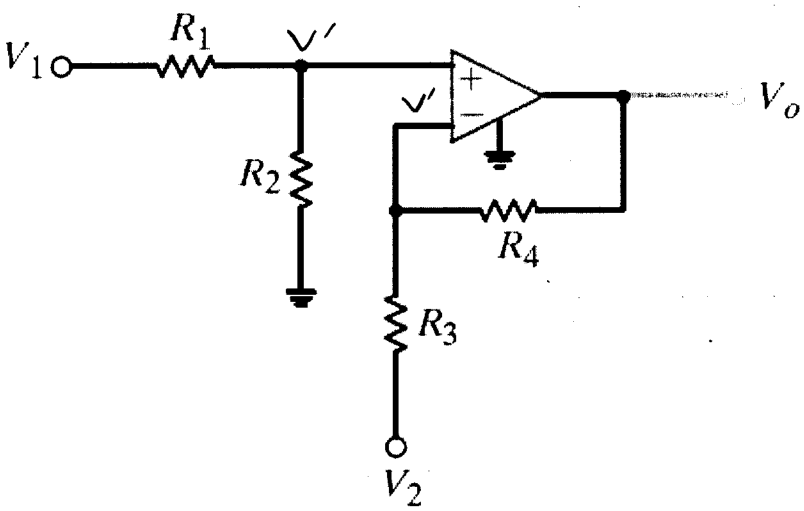


Figure P4.47

SOLUTION:

$$V_o = K_1 V_1 - K_2 V_2$$

$$0 \leq K_1 \leq K_2 + 1$$



KCL at V_+ : $\dfrac{V_1 - V'}{R_1} = \dfrac{V'}{R_2}$

$$V'\left(\frac{1}{R_1}+\frac{1}{R_2}\right)=\frac{V_1}{R_1}$$

$$V'=\left(\frac{R_2}{R_1+R_2}\right)V_1$$

KCL at V_- : $\dfrac{V_O-V'}{R_4}=\dfrac{V'-V_2}{R_3}$

$$V_O=\left(\frac{1}{R_3}+\frac{1}{R_4}\right)R_4V'-\frac{R_4}{R_3}V_2$$

$$V_O=\left(1+\frac{R_4}{R_3}\right)V'-\frac{R_4}{R_3}V_2$$

$$V_O=\left(1+\frac{R_4}{R_3}\right)\left(\frac{R_2}{R_1+R_2}\right)V_1-\frac{R_4}{R_3}V_2$$

$$V_O=K_1V_1-K_2V_2$$

$$K_2=\frac{R_4}{R_3}$$

If $R_2=0\,\Omega$, $K_1=0$

If $R_2\neq 0\,\Omega$ and $R_1=0\,\Omega$

$$K_1=1+\frac{R_4}{R_3}$$

$$K_1=1+K_2$$

$$0 \leq K_1 \leq K_2 + 1$$

4.48 A 170°C maximum temperature digester is used in a paper mill to process wood chips that will eventually become paper. As shown in Fig. P4.48a, three electronic thermometers are placed along its length. Each thermometer outputs 0 V at 0°C, and the voltage changes 25 mV/°C. We will use the average of the three thermometer voltages to find an aggregate digester temperature. Furthermore, 1 volt should appear at V_o for every 10°C of average temperature. Design such an averaging circuit using the op-amp configuration shown in Fig. P4.48b if the final output voltage must be positive.

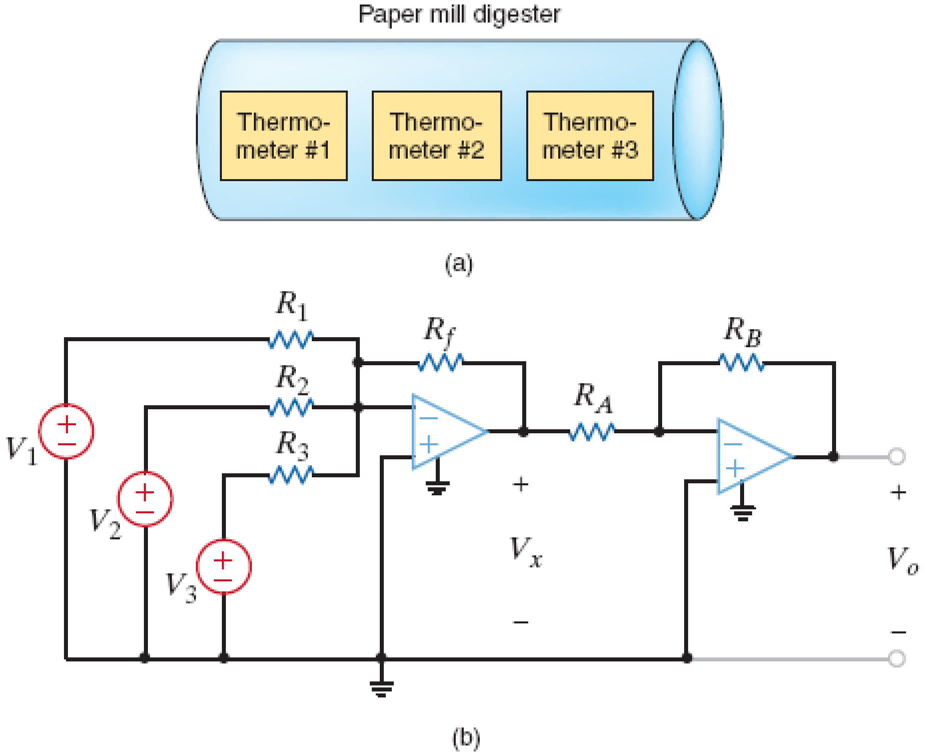
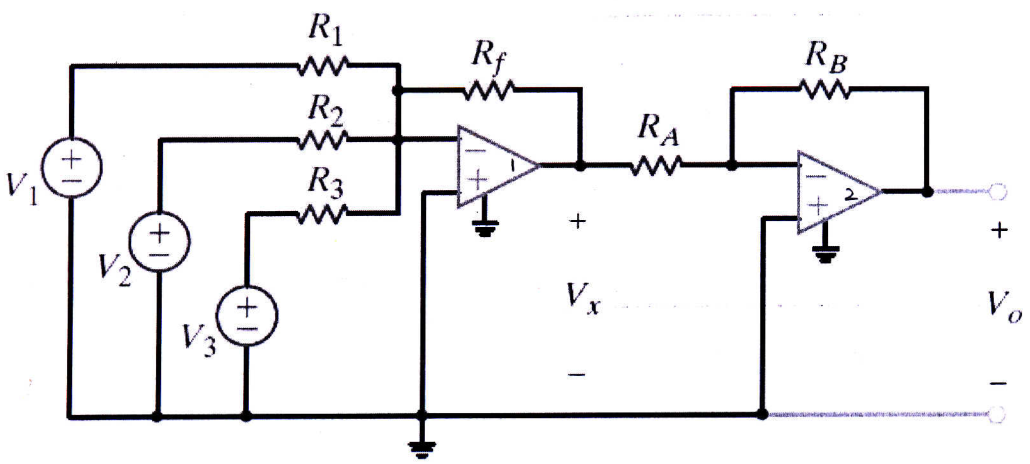


Figure P4.48

SOLUTION:



op-amp #1 is a summer.

op-amp #2 is an inverting op-amp.

$$V_x = -\left[\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right]$$

$$V_o = \frac{-R_B}{R_A}V_x$$

$$V_o = \frac{R_B}{R_A}\left[\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right]$$

Select $\frac{R_F}{R_1} = \frac{R_F}{R_2} = \frac{R_F}{R_3} = 1/3$

$$V_o = \frac{R_B}{R_A}\left(\frac{V_1 + V_2 + V_3}{3}\right)$$

If $\Delta T_1 = 10°C$, $\Delta V = 0.25V$ and $\Delta V_o = 1V$

$$\frac{\Delta V_o}{\Delta V_1} = \frac{R_B}{R_A}\left(1/3\right)$$

$$\frac{\Delta V_o}{\Delta V_1} = \frac{1}{0.25}$$

$$\frac{\Delta V_O}{\Delta V_1} = 4$$

Select $R_A = R_F = 1K\Omega$

$$R_1 = R_2 = R_3 = 3K\Omega$$

Vo should be 4 times average of 3 temperatures.

$$\therefore \left(\frac{V_1+V_2+V_3}{3}\right) \times 4 = V_o$$

$$\therefore \quad \frac{R_B}{R_A} = 12 \Rightarrow \boxed{R_B = 12K\Omega}$$

4.49 A 0.1-Ω shunt resistor is used to measure current in a fuel-cell circuit. The voltage drop across the shunt resistor is to be used to measure the current in the circuit. The maximum current is 20 A. Design the circuit shown in Fig. P4.49 so that a voltmeter attached to the output will read 0 volts when the current is 0 A and 20 V when the current is 20 A. Be careful not to load the shunt resistor, since loading will cause an inaccurate reading.

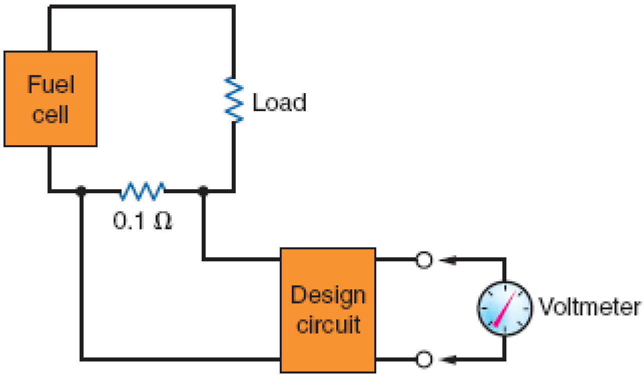
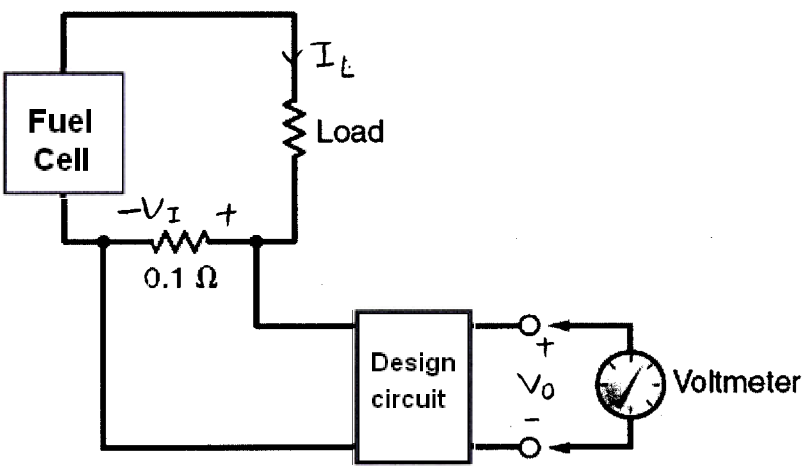


Figure P4.49

SOLUTION:



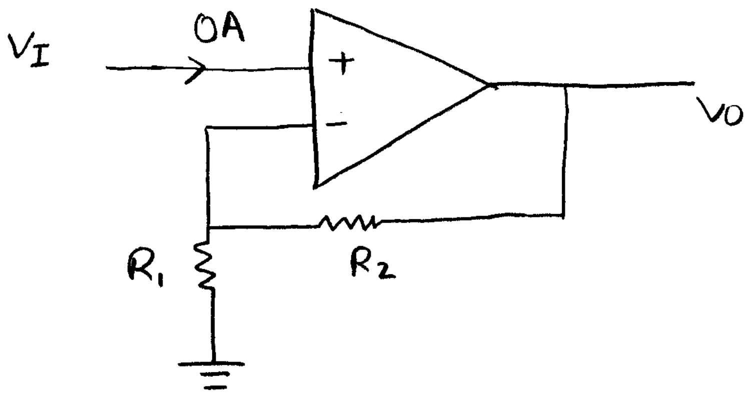
When $I_L = 20A$, $V_I = 0.1 I_L$

$$V_I = 0.1(20)$$

$$V_I = 2V$$

and $V_0 = 20V$.

a gain of 10 is needed with a buffered input. The op-amp should be a non-inverting configuration.



$$\frac{V_O}{V_I} = 1 + \frac{R_2}{R_1}$$

$$\frac{V_O}{V_I} = 10$$

Select $R_1 = 1K\Omega$

$$10 = 1 + \frac{R_2}{1 \times 10^3}$$

$$R_2 = 9K\Omega$$

4.50 Wood pulp is used to make paper in a paper mill. The amount of lignin present in pulp is called the kappa number. A very sophisticated instrument is used to measure kappa, and the output of this instrument ranges from 1 to 5 volts, where 1 volt represents a kappa number of 12 and 5 volts represents a kappa number of 20. The pulp mill operator has asked to have a kappa meter installed on his console. Design a circuit that will employ as input the 1-to 5-volt signal and output the kappa number. An electronics engineer in the plant has suggested the circuit shown in Fig. P4.50.

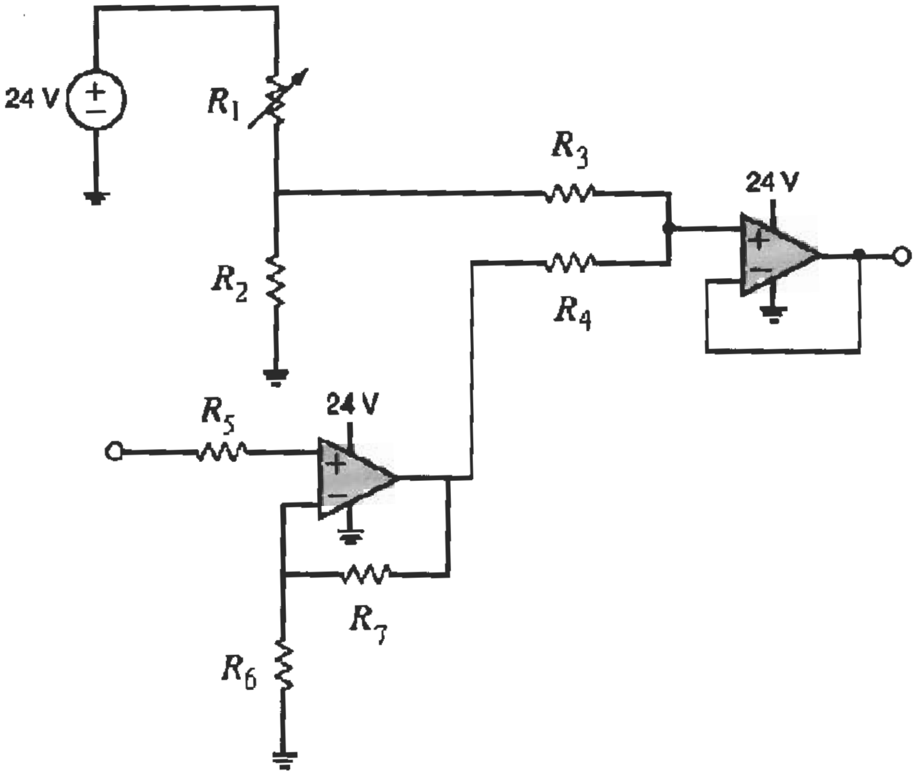
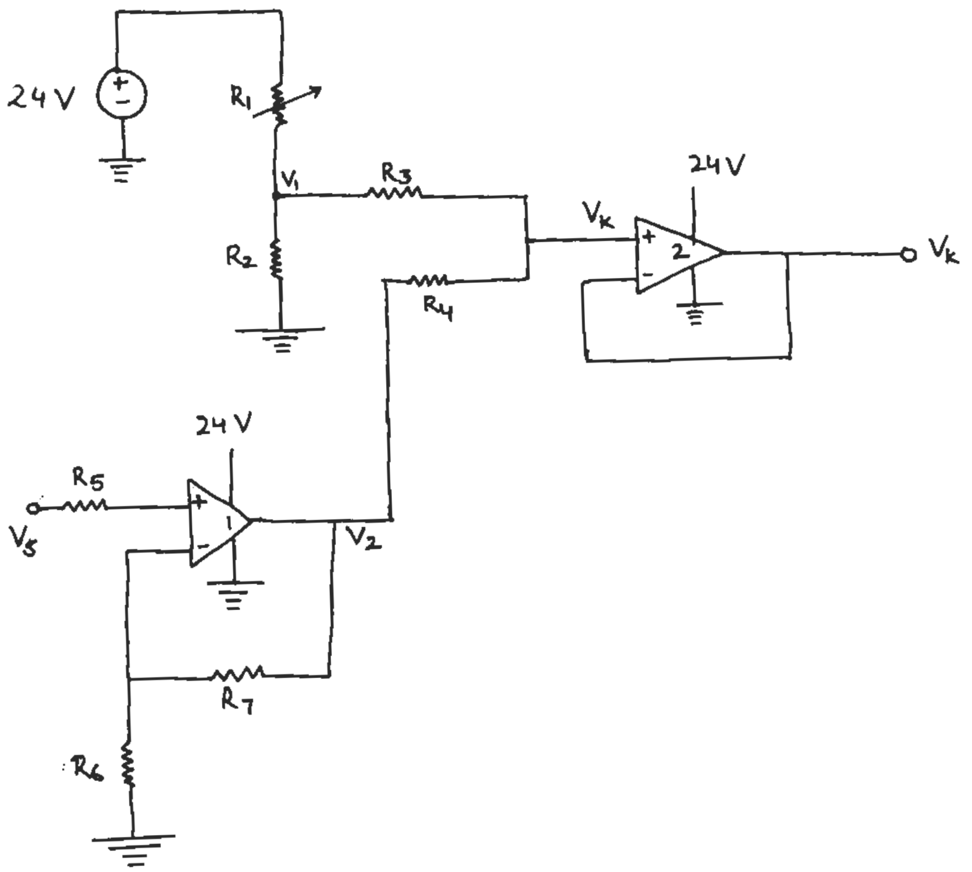


Figure P4.50

If $R_1 = 1k\Omega$, $R_2 = R_3 = R_4 = R_5 = 7.5\ k\Omega$, $R_6 = 19k\Omega$, Find R_7.

Solution: 4.50



KCL at V_1 : $\dfrac{24 - V_1}{R_1} = \dfrac{V_1}{R_2} + \dfrac{V_1 - V_K}{R_3}$ ——— ①

KCL at V_K : $\dfrac{V_1 - V_K}{R_3} = \dfrac{V_K - V_2}{R_4}$ ——— ②

op-amp 1 is at non-inverting configuration :

$$V_2 = V_s\left(1 + \frac{R_7}{R_6}\right) = g\,V_s$$

Let $R_2 = R_3 = R_4 = R_5 = R$

@ V_K : $V_1 = 2V_K - V_2$ ——— ④

@ V_1 : $24R = V_1(2R_1 + R) - V_K R_1$ ——— ⑤

yields $V_K = \dfrac{24R}{3R_1 + 2R} + \dfrac{g(2R_1 + R)}{3R_1 + 2R} V_s$ ——— ⑥

Also, $V_K = b + mV_s$

At $V_s = 1\,V$, $V_K = 12\,V$ and at $V_s = 5\,V$, $V_K = 20\,V$

Therefore $m = \dfrac{\Delta V_K}{\Delta V_s} = \dfrac{8}{4} = 2$ and $b = 10$

$$V_K = 10 + 2V_s = \frac{24R}{3R_1 + 2R} + g\frac{(2R_1 + R)}{3R_1 + 2R} V_s \quad \text{———} \quad (7)$$

We have, $R_1 = 1\ k\Omega$, $R = 7.5\ k\Omega$

Substituting the values of R_1 and R in equation (7), we get

$$V_K = 10 + 2V_s = 10 + \frac{9.5}{18} g V_s$$

$$\therefore 2V_s = \frac{9.5}{18} g V_s$$

$$\Rightarrow g = \frac{36}{9.5} = 3.79$$

From equation (3), we get $1 + \frac{R_7}{R_6} = 3.79$

$$R_6 = 19\ k\Omega$$

$$\therefore \boxed{R_7 = 53.01\ k\Omega}$$

4.51 An operator in a chemical plant would like to have a set of indicator lights that indicate when a certain chemical flow is between certain specific values. The operator wants a RED light to indicate a flow of at least 10 GPM (gallons per minute), RED and YELLOW lights to indicate a flow of 60 GPM, and RED, YELLOW, and GREEN lights to indicate a flow rate of 80 GPM. The 4–20 mA flow meter instrument outputs 4 mA when the flow is zero and 20 mA when the flow rate is 100 GPM.

An experienced engineer has suggested the circuit shown in Fig. P4.51. The 4–20 mA flow meter and 250 Ω resistor provide a 1–5 V signal, which serves as one input for the three comparators. The light bulbs will turn on when the negative input to a comparator is higher than the positive input. Using this network, design a circuit that will satisfy the operator's requirements.

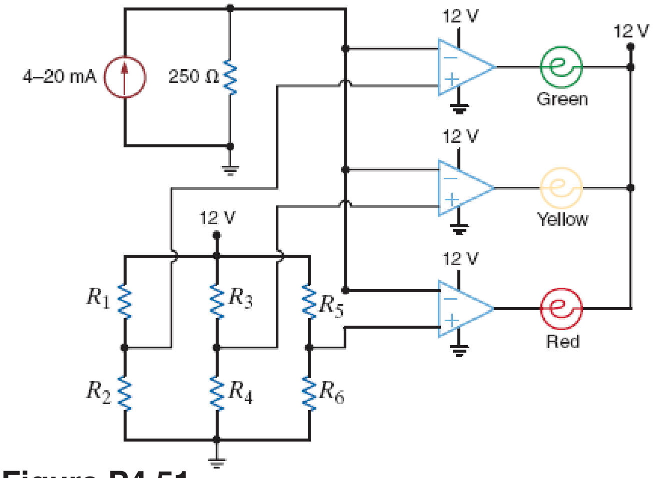
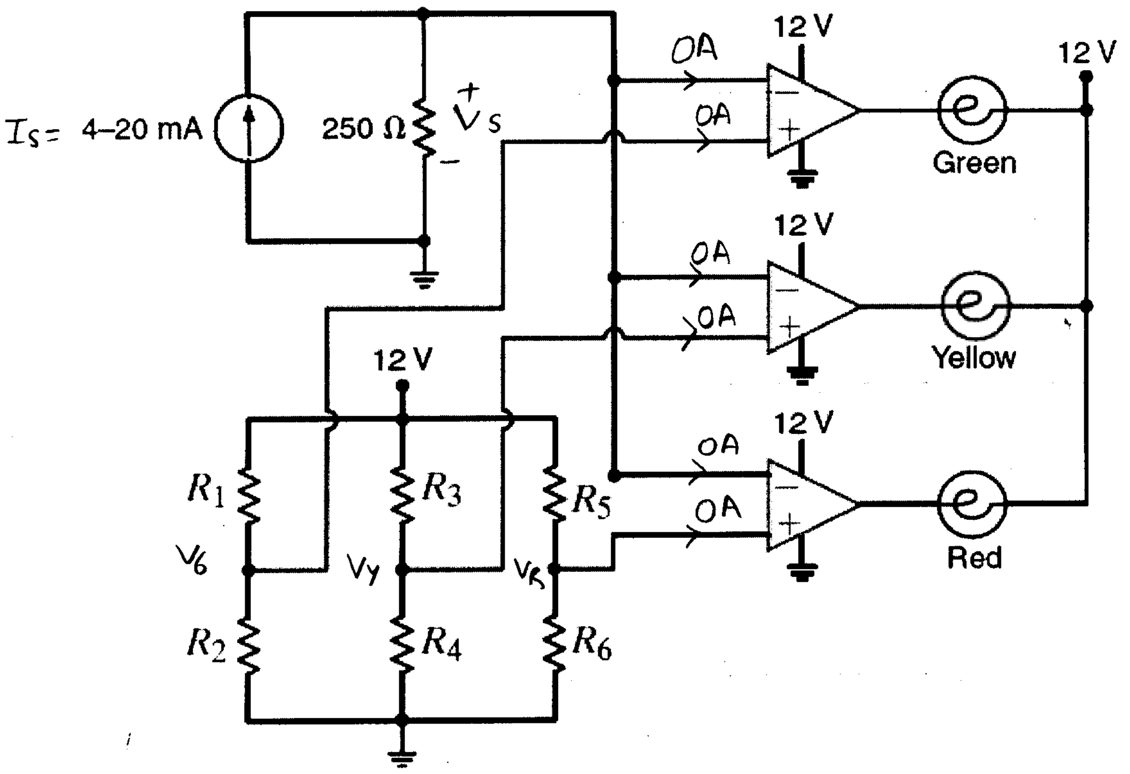


Figure P4.51

SOLUTION:



want $V_6 = V_5$ when flow = 806 Pm

$$I_S = m(\text{flow}) + b$$

flow = 0, $I_S = 4mA$

flow = 100, $I_S = 20mA$

$$4\times10^{-3} = m(0) + b$$
$$b = 4\times10^{-3}$$

$$20\times10^{-3} = m(100) + 4\times10^{-3}$$
$$m = 0.16\times10^{-3}$$

$$I_S = 0.16\times10^{-3}\,\text{flow} + 4\times10^{-3}$$

at flow = 806 Pm, $I_S = 16.8mA$

$$V_S = 250 I_S$$
$$V_S = 250(16.8\times10^{-3})$$
$$V_S = 4.2V$$

$$V_0 = \left(\frac{R_2}{R_1+R_2}\right)(12)$$

Select $R_2 = 1K\Omega$

$R_1 = 1.86\ K\Omega$

at flow = 60 GPM

$I_s = 0.16 \times 10^{-3}(60) + 4 \times 10^{-3}$

$I_s = 13.6\ mA$

$V_s = 250\ (13.6 \times 10^{-3})$

$V_s = 3.4V$

Want $V_y = 3.4V$

$$V_y = \frac{12 R_4}{R_4 + R_3}$$

$$3.4 = \frac{12 R_4}{R_4 + R_3}$$

Select $R_4 = 1K\Omega$, $R_3 = 2.53K\Omega$

at flow = 10 GPM

$$I_s = 0.16 \times 10^{-3}(10) + 4 \times 10^{-3}$$

$$I_s = 5.6\,mA$$

$$V_s = 250(5.6 \times 10^{-3})$$

$$V_s = 1.4\,V$$

$$V_R = 1.4\,V$$

$$1.4 = \frac{12 R_6}{R_6 + R_5}$$

Select $R_6 = 1k\Omega$, $R_5 = 7.57\,k\Omega$

Select $R_2 = R_4 = R_6 = 1k\Omega$

$$R_1 = 1.86\,k\Omega$$

$$R_3 = 2.53\,k\Omega$$

$$R_5 = 7.57\,k\Omega$$

4.52 An industrial plant has a requirement for a circuit that uses a input the temperature of a vessel and outputs a voltage proportional to the vessel's temperature. The vessel's temperature ranges from 0^0 C to 500^0C, and the corresponding output of the circuit should range from 0 to 10V. A RTD (resistive thermal device), which is a linear device whose resistance changes with temperature according to the plot in Fig. P4.52a, is available. The problem then is to use this RTD to design a circuit that employs this device as an input and produces a 0-to 12-V signal at the output, where 0 V corresponds to 0^0C and 12 V corresponds to 500^0C. An engineer familiar with this problem suggests the use of the circuit shown in Fig. P4.52b in which the RTD bridge circuit provides the input to a standard instrumentation amplifier. Determine the component values in this network needed to satisfy the design requirements. If $R_1 = R_2 = R_3 = 100\Omega$, $R_4 = R_5 = 4K\Omega$ Find R_G.

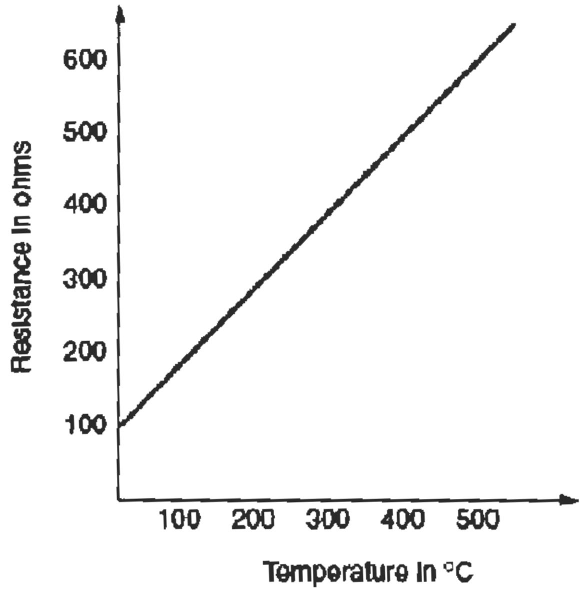


Figure P4.52a

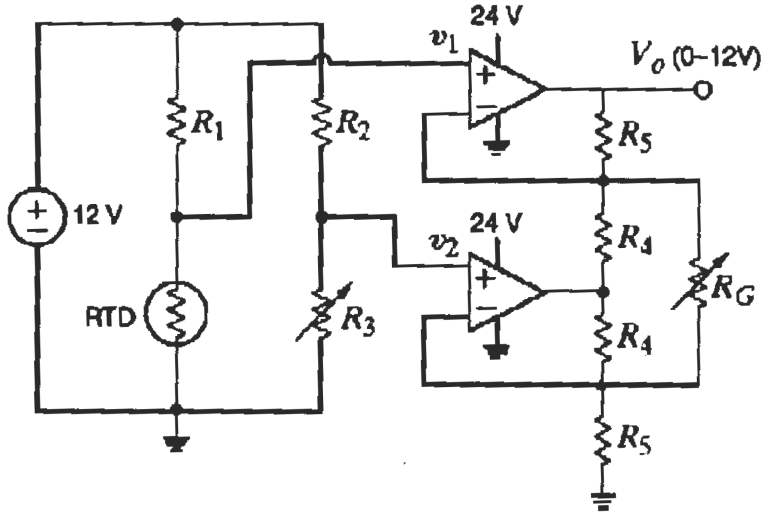
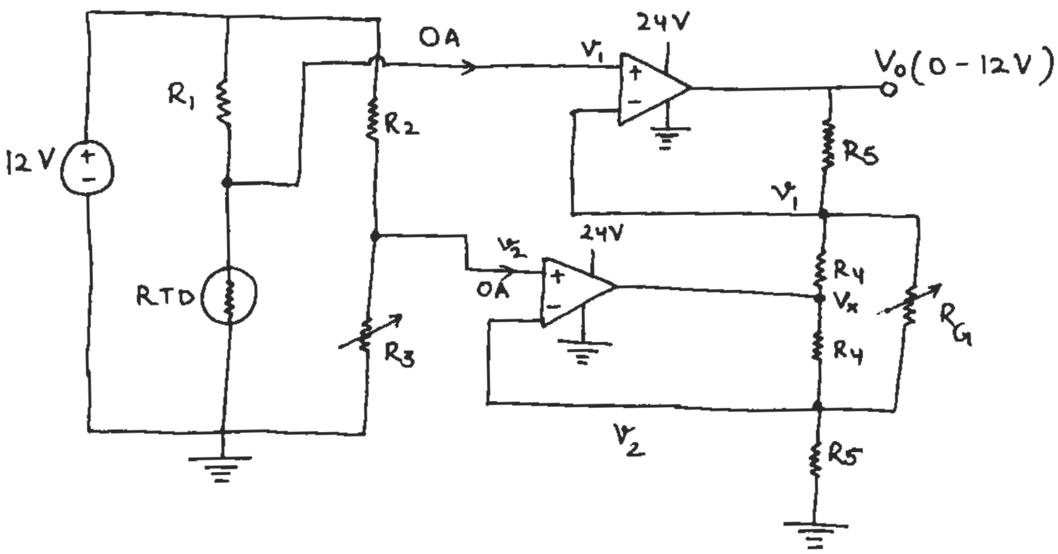


Figure P4.52b

Solution: 4.52



KCL at R_{RTD} : $\dfrac{12-V_1}{R_1} = \dfrac{V_1}{R_{RTD}}$

$$\Rightarrow \quad 12\,R_{RTD} = V_1\,(R_1 + R_{RTD})$$

$$V_1 = \frac{12\,R_{RTD}}{(R_1 + R_{RTD})} \quad \text{———} \quad (1)$$

KCL at V_{2+} : $V_2 = \dfrac{12\,R_3}{R_2 + R_3}$ ——— (2)

$R_{RTD}\,(T)$: $R_{RTD} = K_1 + K_2 T$

At $T = 0^\circ c$, $R_{RTD} = K_1 = 100\,\Omega$

At $T = 500^\circ c$, $R_{RTD} = 600\,\Omega = 100 + K_2(500)$

$$K_2 = 1\,\Omega/^\circ c$$

$$\Rightarrow \quad R_{RTD} = 100 + T \quad \text{———} \quad (3)$$

We have $R_1 = R_2 = R_3 = 100\,\Omega$

Now $\dfrac{12-V_1}{100} = \dfrac{V_1}{100+T}$

$$\Rightarrow \quad 12 - V_1 = \frac{V_1}{1 + T/100} \quad \text{———} \quad (4)$$

Substituting $R_2 = R_3 = 100\,\Omega$ in equation (2), we get

$$V_2 = \frac{12 \times 100}{100 + 100} = 6\,V$$

KCL at v_1 at $R_4 - R_5$ node :

$$\frac{v_0 - v_1}{R_5} = \frac{v_1 - v_2}{R_G} + \frac{v_1 - v_x}{R_4} \qquad \text{—— } ⑤$$

KCL at v_2 at $R_5 - R_4$ node:

$$\frac{v_x - v_2}{R_4} + \frac{v_1 - v_2}{R_G} = \frac{v_2}{R_5} \qquad \text{—— } ⑥$$

We have $R_4 = R_5 = 4\,k\Omega$

From equation ⑤, we get

$$\frac{v_0 - v_1}{R_4} = \frac{v_1 - v_2}{R_G} + \frac{v_1 - v_x}{R_4} \qquad \text{—— } ⑦$$

From equation ⑥, we get

$$\frac{v_x - v_2}{R_4} + \frac{v_1 - v_2}{R_G} = \frac{v_2}{R_4} \qquad \text{—— } ⑧$$

From equations ⑦ and ⑧, we get

$$V_0 = 24\left(\frac{100 + T}{200 + T} - \frac{1}{2}\right)\left(1 + \frac{R_4}{R_G}\right)$$

At $T = 0$, $V_0 = 0\,V$

At $T = 500^\circ C$

$$V_0 = 24\left(\frac{600}{700} - \frac{1}{2}\right)\left(1 + \frac{4 \times 10^4}{R_G}\right) = 12$$

$$\boxed{R_G = 10\,k\Omega}$$

4FE-1 Given the summing amplifier shown in Fig. 4PFE-1, select the values of R_2 that will produce an output voltage of -3 V.

a. 4.42 kΩ b. 6.33 kΩ
c. 3.6 kΩ d. 5.14 kΩ

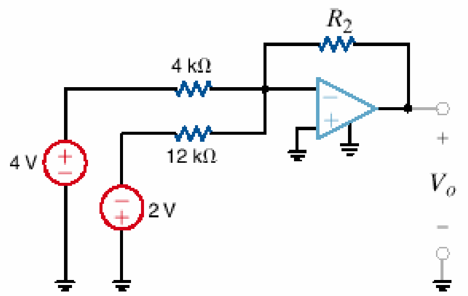


Figure 4PFE-1

SOLUTION:

The correct answer is *c*.

$$V_o = \left(\frac{-R_2}{4k}\right)(4) - \left(\frac{R_2}{12k}\right)(-2)$$

$$V_o = -3V$$

$$-3 = -1m(R_2) + \frac{1}{6}m(R_2)$$

$$-\frac{5}{6}m(R_2) = -3$$

$$R_2 = 3.6k\Omega$$

4FE-2 Determine the output voltage V_o of the summing op-amp circuit shown in Fig. 4PFE-2.

a. 6 V b. 18 V

c. 9 V d. 10 V

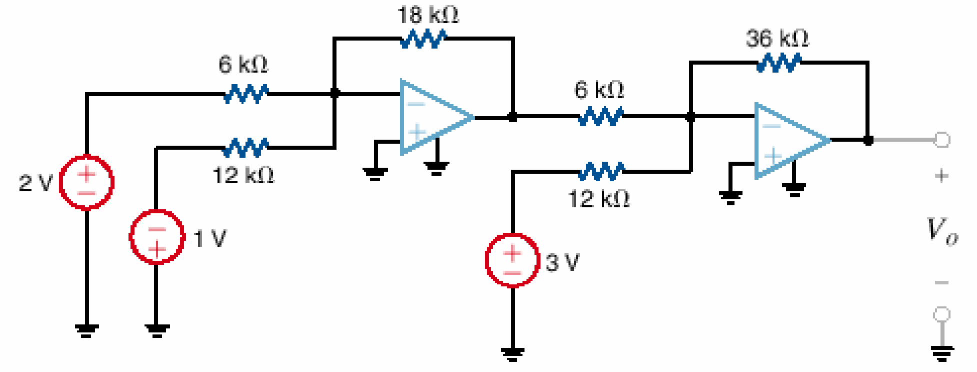
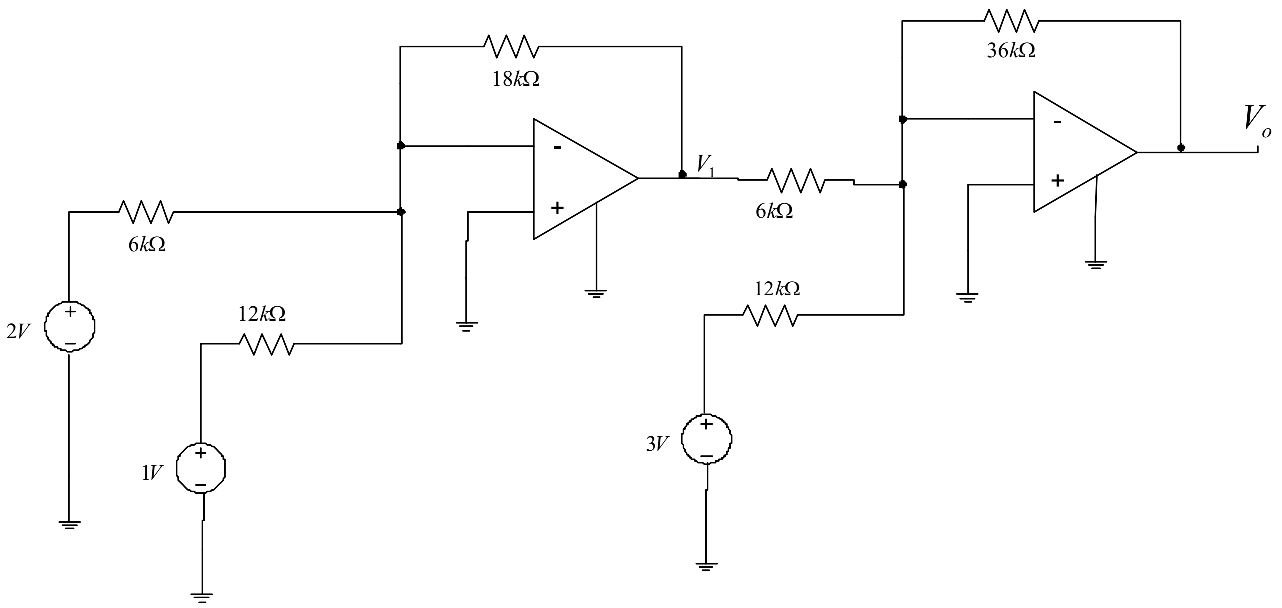


Figure 4PFE-2

SOLUTION:



The correct answer is *b*.

$$V_1 = -2\left(\frac{18k}{6k}\right)(4) + 1\left(\frac{18k}{12k}\right) = -4.5V$$

$$V_0 = -V_1\left(\frac{36k}{6k}\right) - 3\left(\frac{36k}{12k}\right)$$

$$V_0 = 4.5\left(\frac{36k}{6k}\right) - 3\left(\frac{36k}{12k}\right)$$

$$V_0 = 18V$$

4FE-3 What is the output voltage V_o in Fig. 4PFE-3?

a. -5 V b. 6 V

c. 4 V d. -7 V

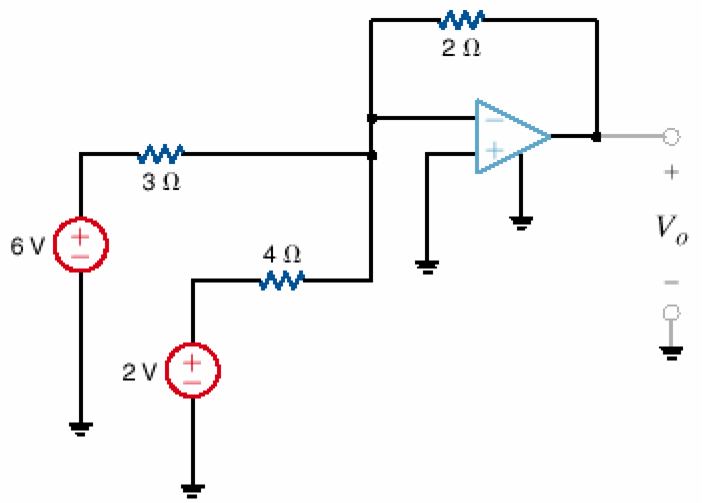
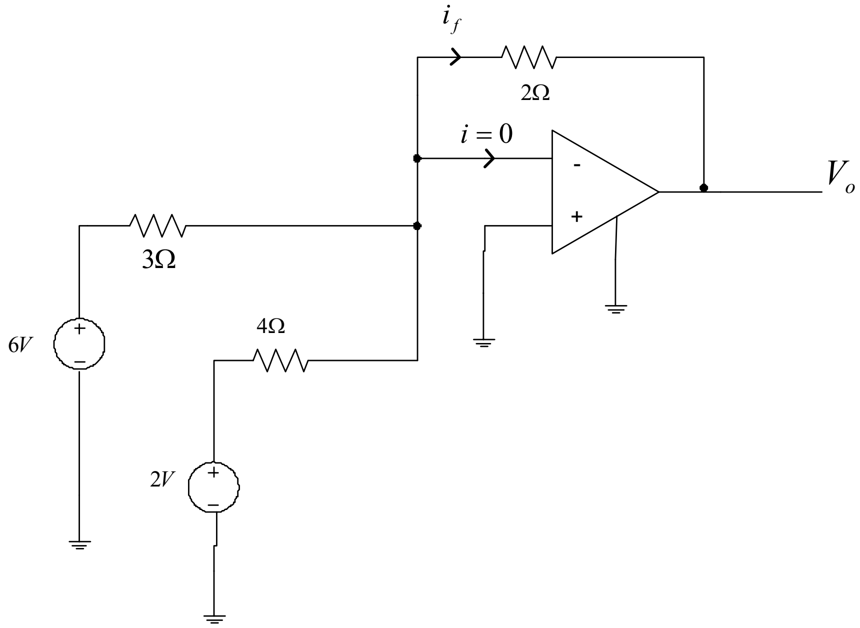


Figure 4PFE-3

SOLUTION:



The correct answer is *a*.

$$i_f = \frac{V_1}{R_1} + \frac{V_2}{R_2} = \frac{6}{3} + \frac{2}{4} = 2.5A$$

$$V_0 = -i_f R_f = -(2.5)(2)$$

$$V_0 = -5V$$

4FE-4 What value of R_f in the op-amp circuit of Fig. 4PFE-4 is required to produce a voltage gain of 50?

a. 135 kΩ

b. 210 kΩ

c. 180 kΩ

d. 245 kΩ

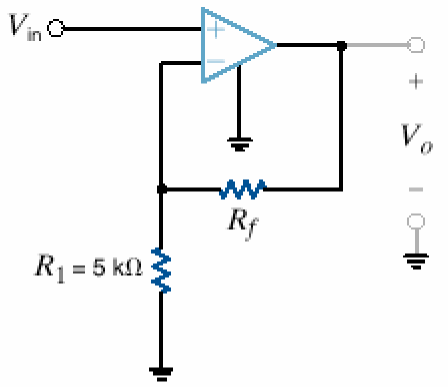


Figure 4PFE-4

SOLUTION:

The correct answer is *d*.

The op-amp is a noninverting op-amp.

$$A = 1 + \frac{R_f}{R_1}$$

$$R_f = (A - 1)R_1$$

$$R_f = (50 - 1)5k = 245k\Omega$$

4FE-5 What is the voltage V_o in the circuit in Fig. 4PFE-5?

a. 3 V

b. 6 V

c. 8 V

d. 5 V

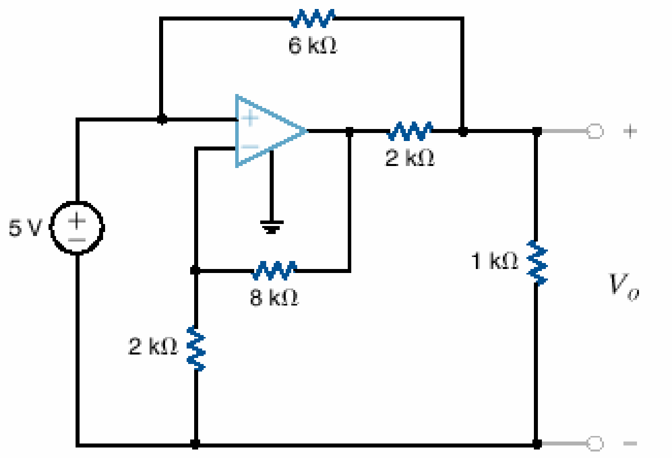
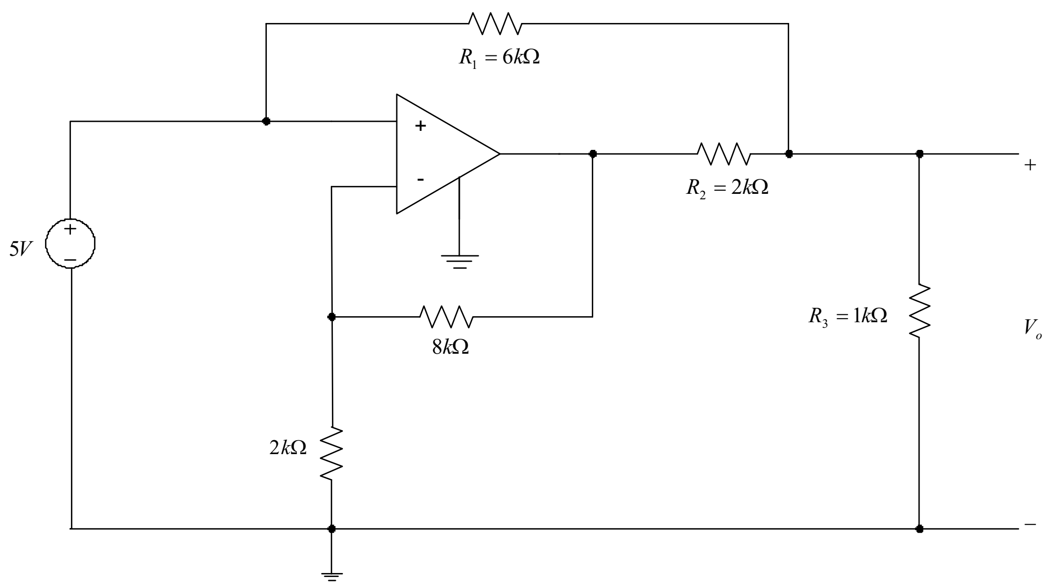


Figure 4PFE-5

SOLUTION:



The correct answer is *c*.

The 8kΩ and 2kΩ resistors make up a noninverting op-amp.

$$V_1 = \left(1 + \frac{8k}{2k}\right)5 = 25V$$

Use nodal analysis at node A:

$$\frac{V_o}{R_3} + \frac{V_o - V_i}{R_1} + \frac{V_o - 25}{2k} = 0$$

$$\frac{V_o}{1k} + \frac{V_o - 5}{6k} + \frac{V_o - 25}{2k} = 0$$

$$6V_o + V_o - 5 + 3V_o - 75 = 0$$

$$10V_o = 80$$

$$V_o = 8V$$

5.1 Find I_o in the network in Fig. P5.1 using linearity and the assumption that $I_o = 1$ mA.

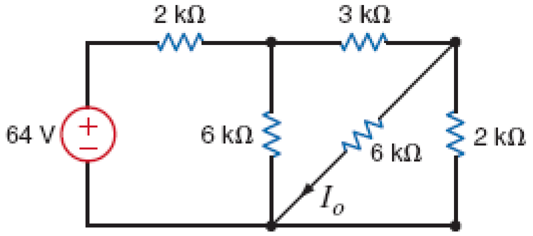
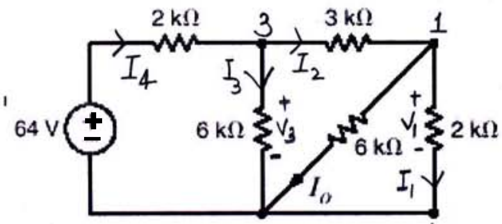


Figure P5.1

SOLUTION:



Assume $I_0 = 1mA$

$V_1 = I_0(6k) = 1m(6k) = 6V$

$I_1 = \frac{6}{2k} = 3mA$

KCL at 1: $I_2 = I_0 + I_1$

$I_2 = 1m + 3m = 4mA$

KVL around right outer loop:

$V_3 = I_2(3k) + V_1 = 4m(3k) + 6 = 18V$

KCL at 3: $I_4 = I_3 + I_2$

$I_4 = \frac{V_3}{6k} + 4m = \frac{18}{6k} + 4m = 7mA$

KVL around left loop:

$V_S = I_4(2k) + V_3 = 2k(7m) + 18 = 32V$

The actual value is $V_S = 64V$

$$\frac{32}{1m} = \frac{64}{x}$$

$$x = \frac{64}{32}(1m) = I_0 = 2mA$$

5.2 Find I_o in the network in Fig. P5.2 using linearity and the assumption that $I_o = 1$ mA.

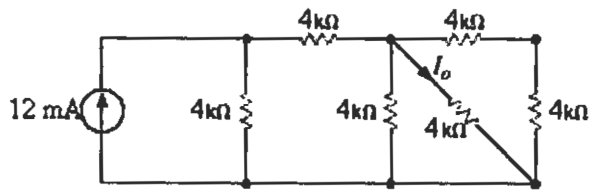
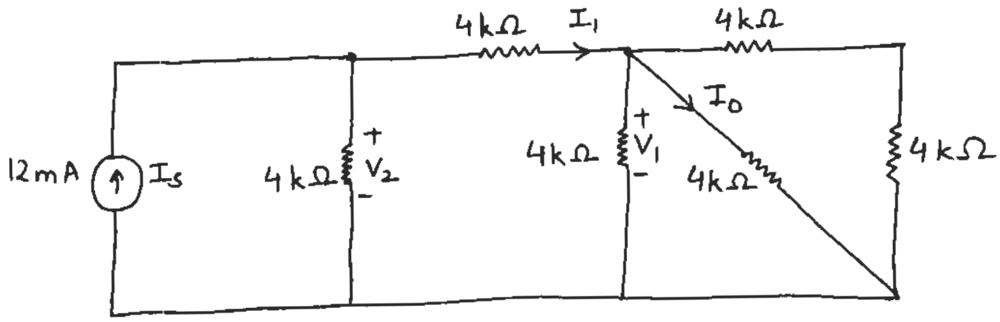


Figure P5.2

Solution: 5.2



If $I_o = 1\,\text{mA}$, $V_1 = I_o(4000) = 4\,\text{V}$

$$I_1 = \frac{V_1}{4000} + I_o + \frac{V_1}{8000} = 2.50\,\text{mA}$$

$$V_2 = 4000 I_1 + V_1 = 14.0\,\text{V}$$

$$I_s = \frac{V_2}{4000} + I_1 = 6.00\,\text{mA}$$

But I_s actually equals 12 mA

So, $I_o = 10^{-3} \times \dfrac{12\times10^{-3}}{6\times10^{-3}}$

$$\boxed{I_o = 2.00\,\text{mA}}$$

5.3 Find I_o in the network in Fig. P5.3 using linearity and the assumption that $I_o = 1$ mA.

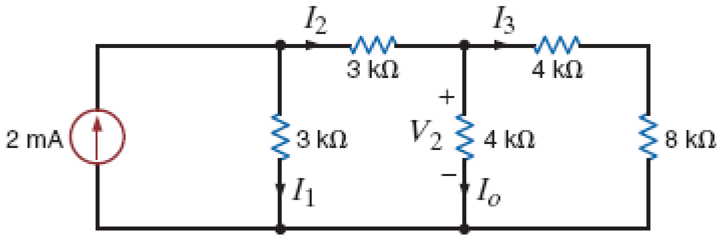
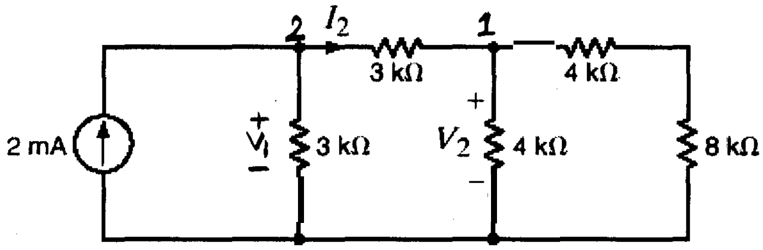


Figure P5.3

SOLUTION:



Assume $I_0 = 1mA$.

$V_2 = 4k(I_0) = 4k(1m) = 4V$

KCL at 1: $I_2 = I_3 + I_0$

$I_2 = \frac{V_2}{12k} + 1m = \frac{4}{12k} + 1m = 1.33mA$

KVL around middle loop:

$V_1 = I_2(3k) + V_2 = 1.33m(3k) + 4 = 8V$

KCL at 2: $I_S = I_1 + I_2$

$I_S = \frac{V_1}{3k} + 1.33m = \frac{8}{3k} + 1.33m = 4mA$

Actually, $I_S = 2mA$.

$I_0 = 1m\left(\frac{2m}{4m}\right) = 0.5mA$

5.4 Find V_o in the network in Fig. P5.4 using linearity and the assumption that $V_o = 1$ V.

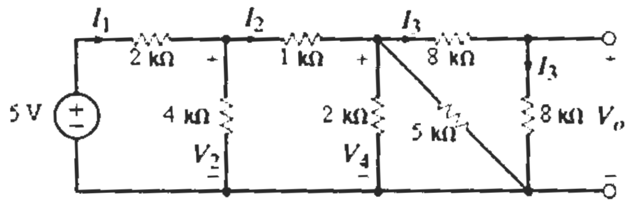
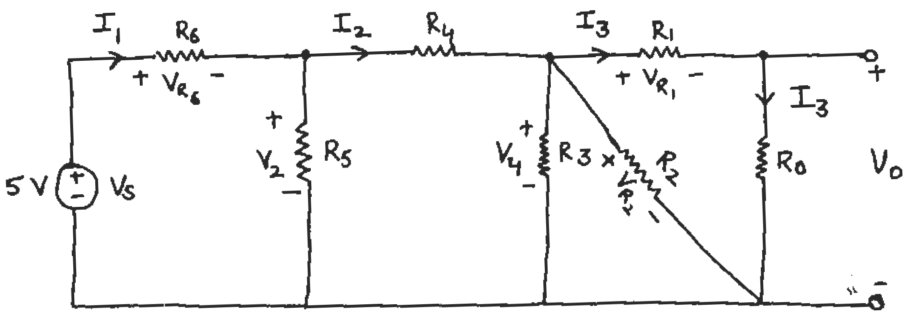


Figure P5.4

Solution: 5.4



$R_o = R_1 = 8k\Omega$, $R_2 = 5k\Omega$, $R_3 = R_6 = 2k\Omega$, $R_4 = 1k\Omega$, $R_5 = 4k\Omega$

If $V_o = 1V$, $I_3 = \frac{V_o}{R_o} = \frac{1}{8}$ mA

$V_{R_1} = I_3 R_1 = 1V$

$V_{R_2} = V_{R_1} + V_o = 2V$, $I_{R_2} = 0.40$ mA

$V_4 = V_{R_2} = 2V$,

$I_2 = \frac{V_4}{R_3} + \frac{V_{R_2}}{R_2} + I_3 = 1.53$ mA

$V_2 = I_2 R_4 + V_4 = 3.53$ V

$I_1 = \frac{V_2}{R_5} + I_2 = 2.41$ mA

$V_S = I_1 R_6 + V_2 = 8.35$ V

But V_S actually equals 5V

So, $V_o = (1)\frac{5}{8.35} = 0.598$ V

$$\boxed{V_o = 0.60\text{ V}}$$

5.5 Find I_o in the network in Fig. P5.5 using superposition.

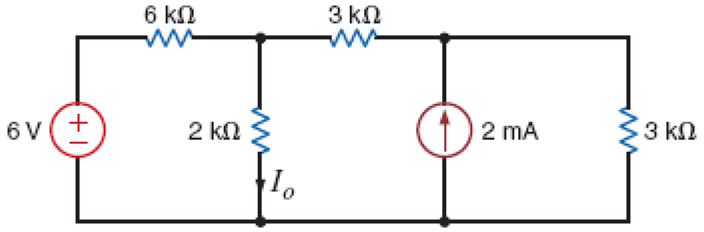
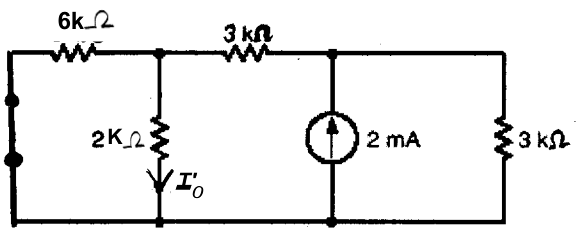
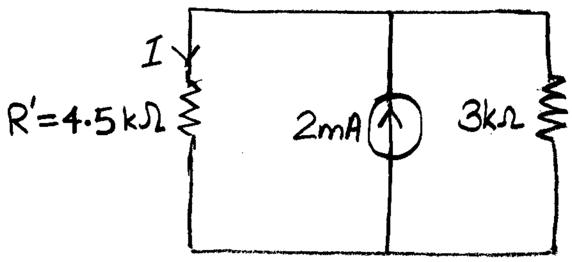


Figure P5.5

SOLUTION:

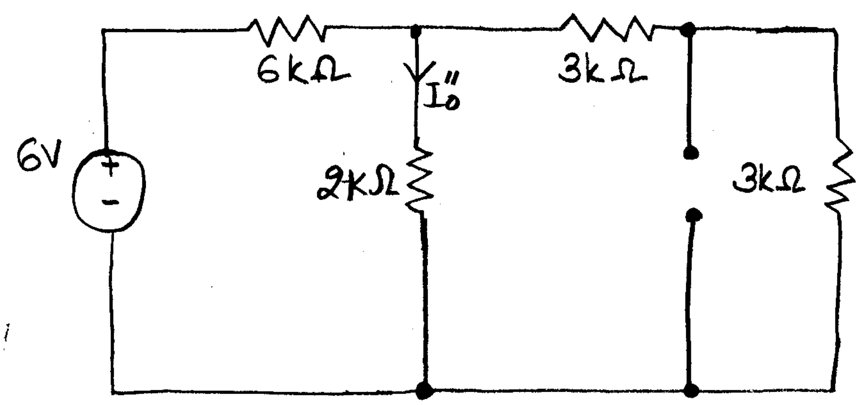


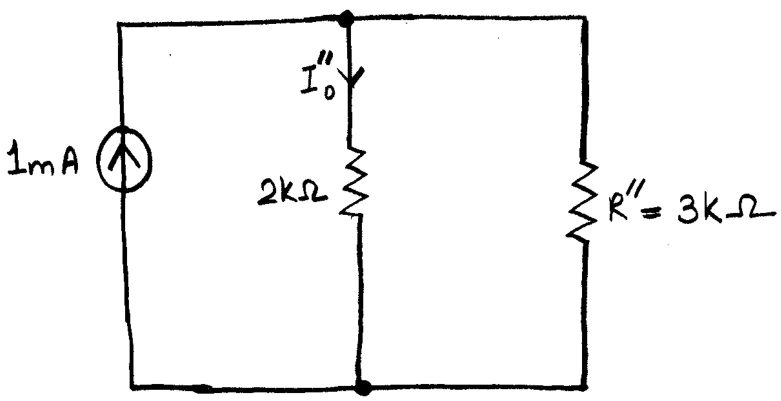
$$R' = (6k \| 2k) + 3k = 4.5k\,\Omega$$



$$I = \frac{3k}{3k+4.5k}(2m) = 0.8mA$$

$$I_o' = \frac{6k}{6k+2k}(0.8m) = 0.6mA$$





$$R'' = (6k \| (3k + 3k)) = 3k\Omega$$

$$I_0'' = \left(\frac{3k}{2k + 3k}\right)(1m) = 0.6mA$$

$$I_0 = 0.6m + 0.6m = 1.2mA$$

5.6 In the network in Fig. P5.6 find I_o using superposition.

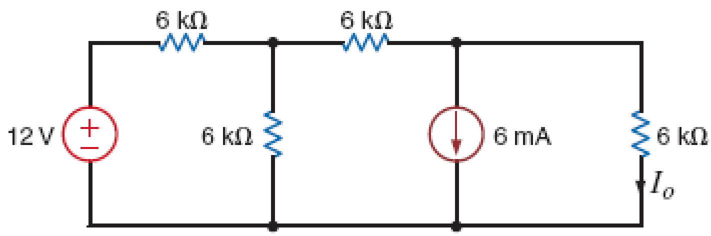
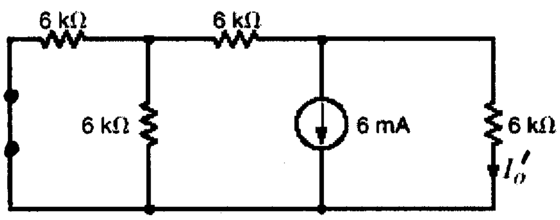
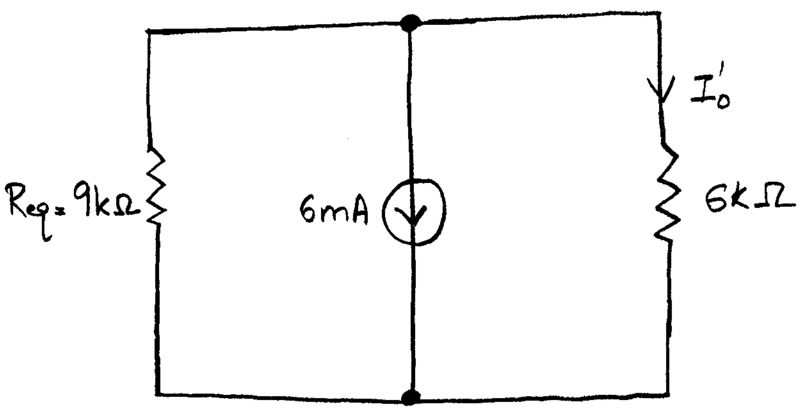


Figure P5.6

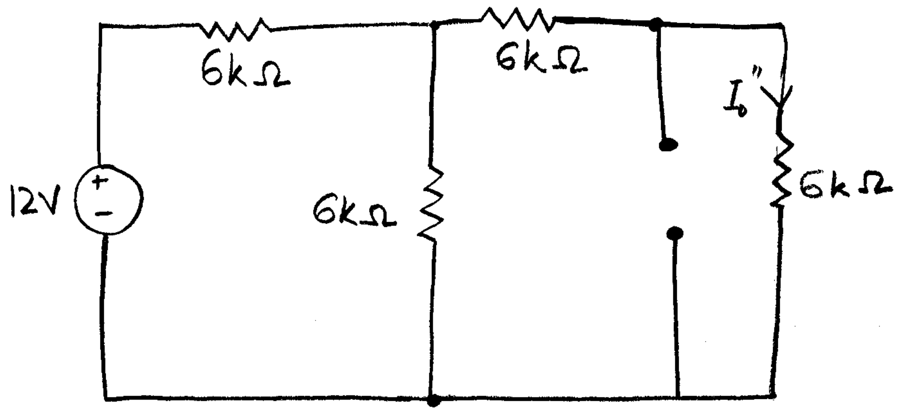
SOLUTION:

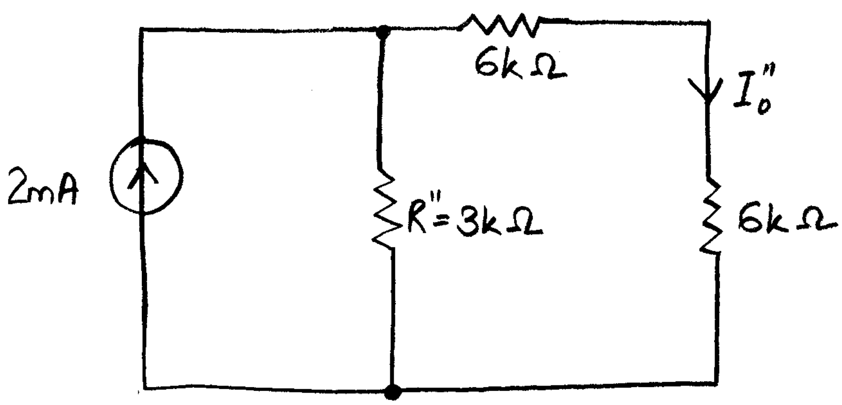


$$R_{eq} = (6k \| 6k) + 6k = 9k\,\Omega$$



$$I_o' = \left(\frac{9k}{9k+6k}\right)(-6m) = -3.6mA$$





$$R'' = (6k \,||\, 6k) = 3k\Omega$$

$$I_o'' = \left(\frac{3k}{3k+6k+6k}\right)(2m) = 0.4mA$$

$$I_o = -3.6m + 0.4m = -3.2mA$$

5.7 Find I_o in the circuit in Fig. P5.7 using superposition.

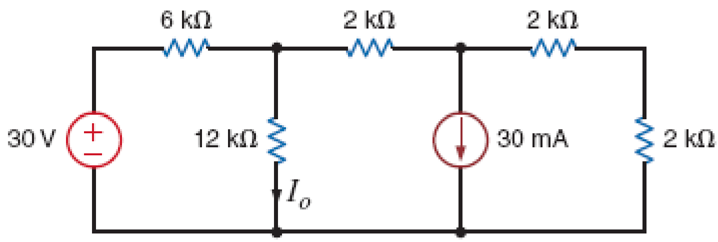
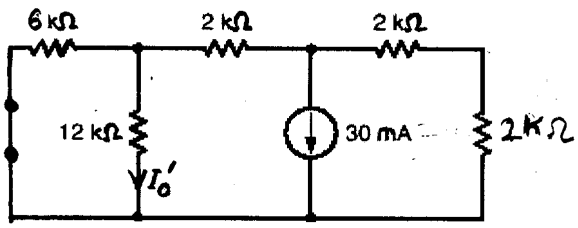
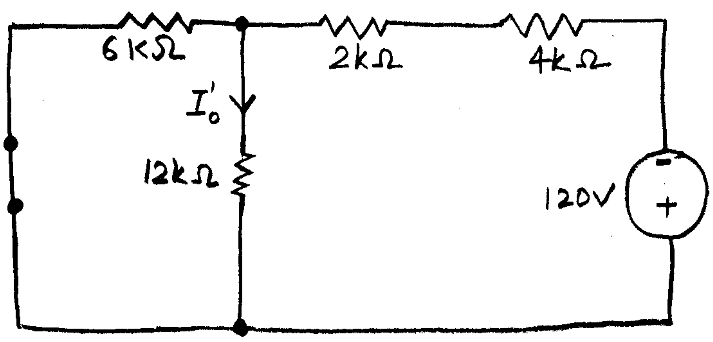
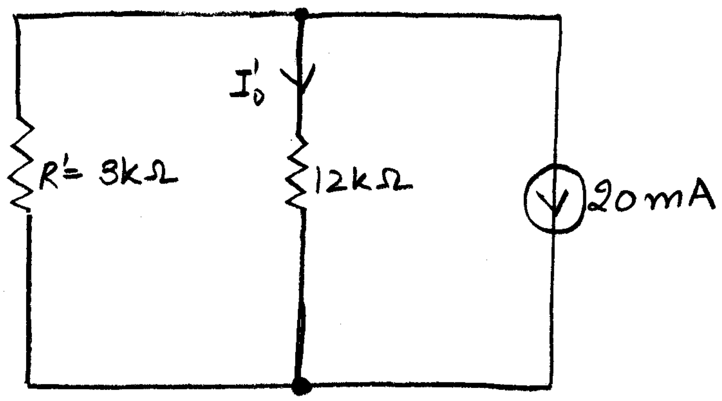


Figure P5.7

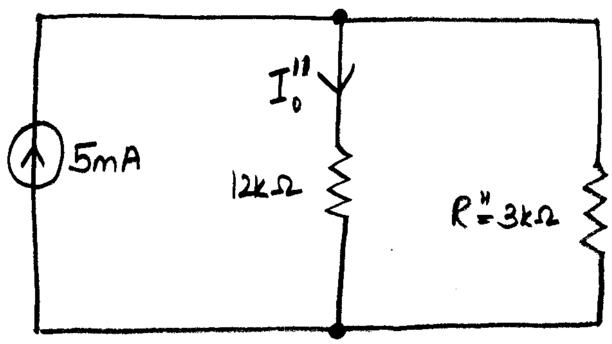
SOLUTION:







$$I_o' = \left(\frac{3k}{3k+12k}\right)(-20m) = -4mA$$



$$R'' = \left(6k \,||\, (2k + 2k + 2k)\right) = 3k\Omega$$

$$I_o'' = \left(\frac{3k}{3k + 12k}\right)(5m) = 1mA$$

$$I_o = -4m + 1m = -3mA$$

5.8 Find V_o in the network in Fig. P5.8 using superposition.

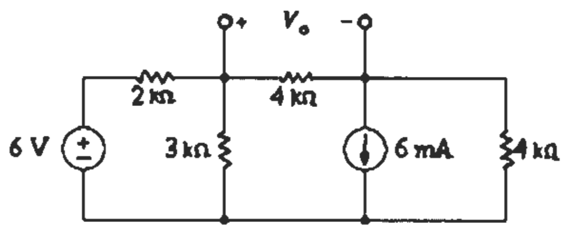
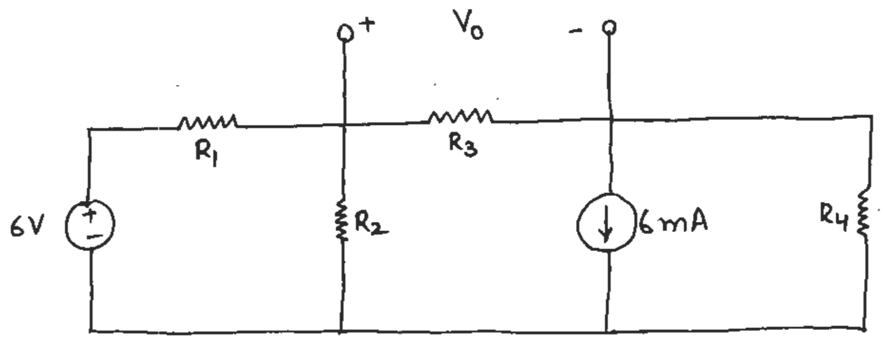
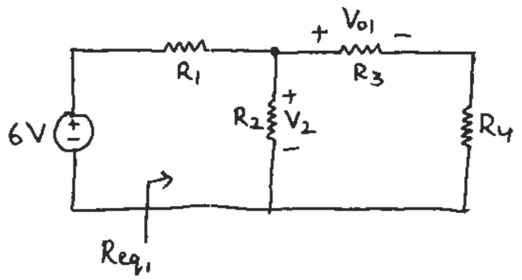


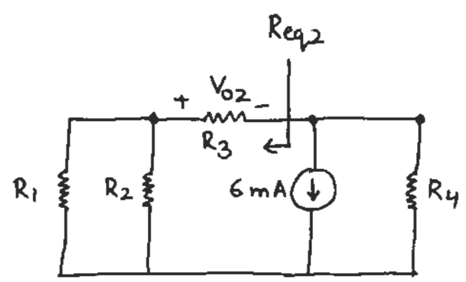
Figure P5.8

Solution: 5.8



$R_1 = 2k\Omega$, $R_2 = 3k\Omega$,
$R_3 = 4k\Omega$, $R_4 = 4k\Omega$



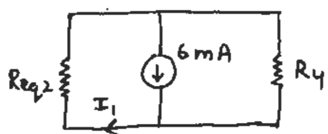


$Req_2 = (R_1 \| R_2) + R_3 = 5.20 k\Omega$

$Req_1 = R_2 \| (R_3 + R_4) = 2.18 k\Omega$

$V_2 = 6\left[\frac{Req_1}{Req_1 + R_1}\right] = 3.13\ V$

$V_{01} = V_2\left[\frac{R_3}{R_3 + R_4}\right] = 1.565\ V$



$I_1 = 6 \times 10^{-3}\left[\frac{R_4}{R_4 + Req_2}\right]$

$I_1 = 2.61\ mA$

$V_{02} = I_1 R_3 = 10.44\ V$

$V_0 = V_{01} + V_{02}$

$\boxed{V_0 = 12.0\ V}$

5.9 Find V_o in the network in Fig. P5.9 using superpositon.

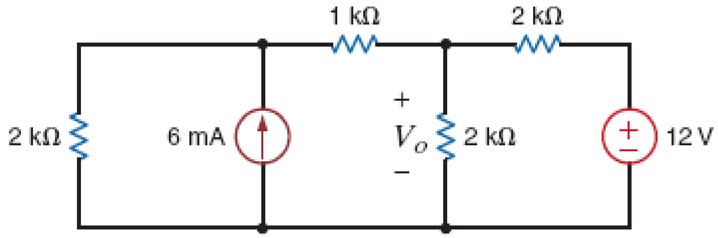
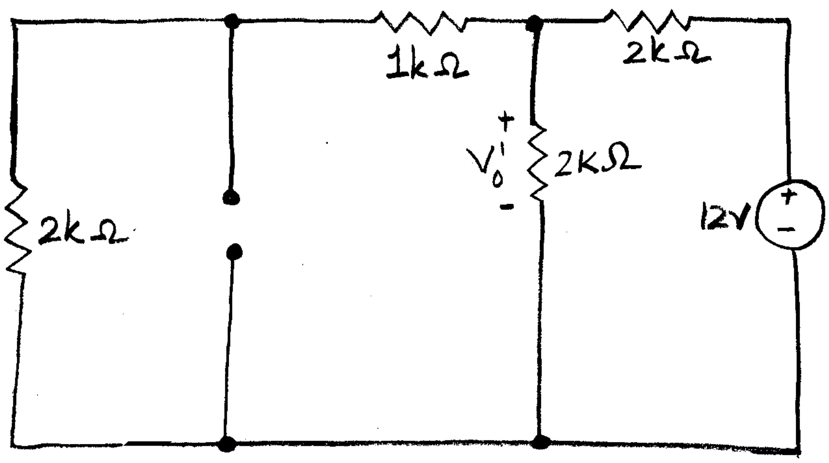
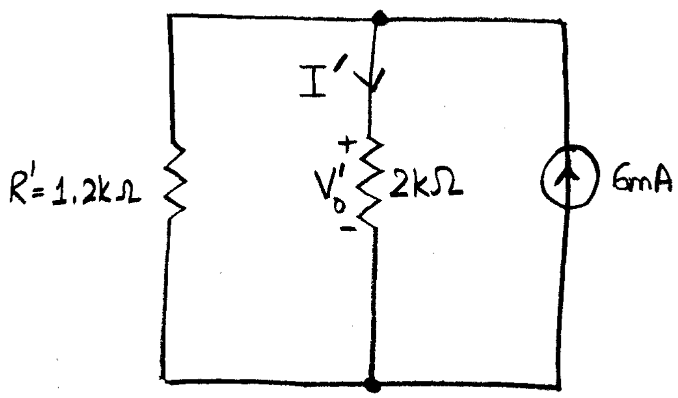


Figure P5.9

SOLUTION:

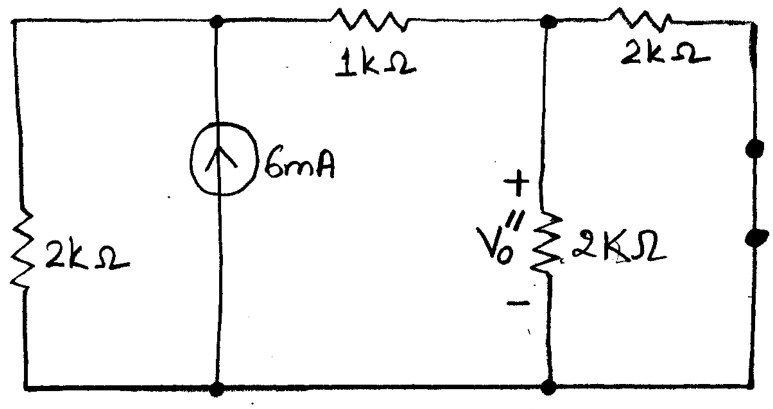


$$R' = 3k \| 2k = 1.2k\Omega$$

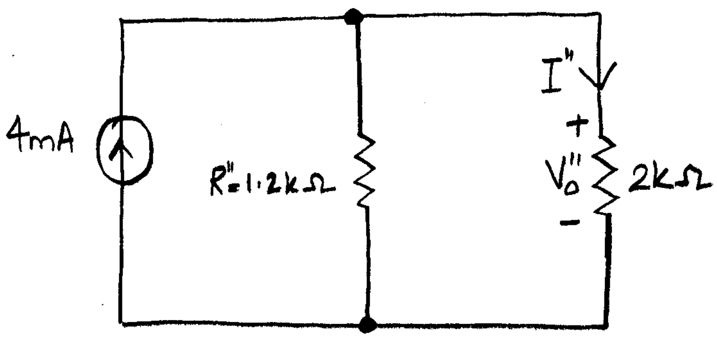


$$I' = \left(\frac{1.2k}{1.2k + 2k}\right)(6m) = 2.25mA$$

$$V_o' = 2k(2.25m) = 4.5V$$



$$R'' = 3k \| 2k = 1.2\,k\Omega$$



$$I'' = \left(\frac{1.2k}{1.2k + 2k}\right)(4m) = 1.5mA$$

$$V_o'' = 2k(1.5m) = 3V$$

$$V_o = 4.5 + 3 = 7.5V$$

5.10 Find V_o in the network in Fig. P5.10 using superposition.

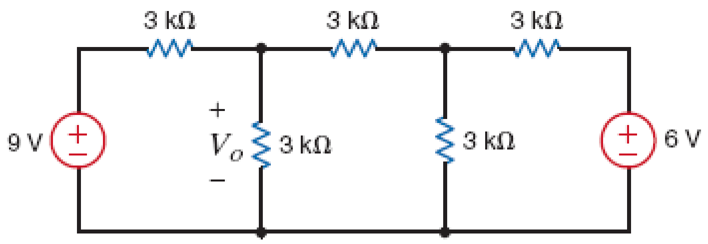
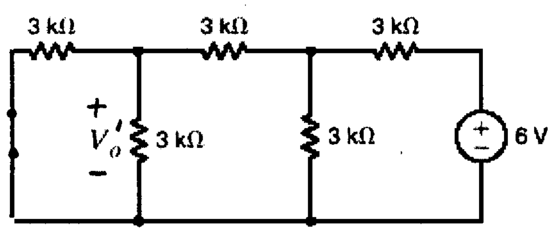
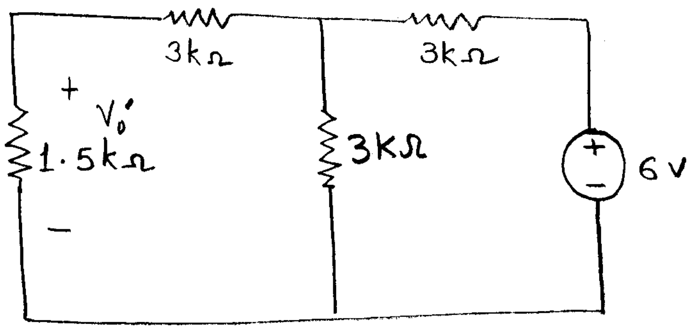


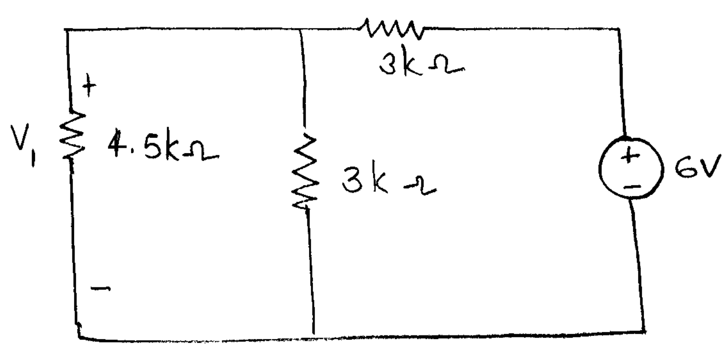
Figure P5.10

SOLUTION:

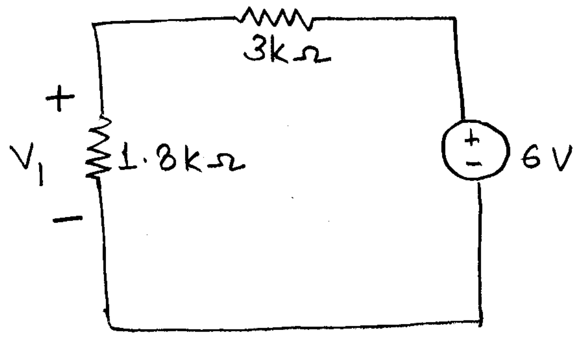


$$R' = 3k \parallel 3k = 1.5k\Omega$$





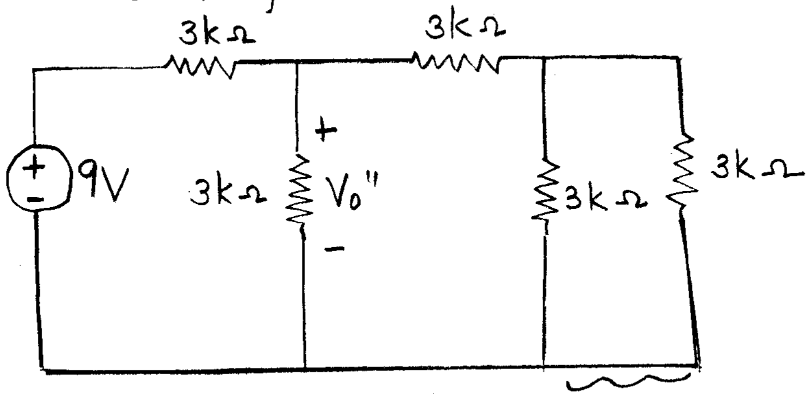
$$V_1 \times \frac{1.5}{4.5} = V_o'$$

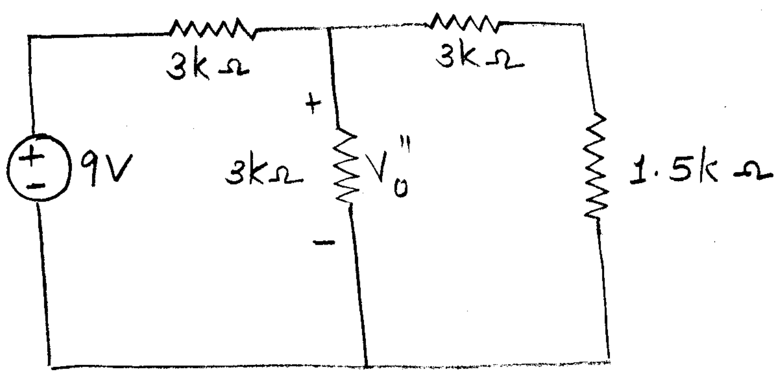


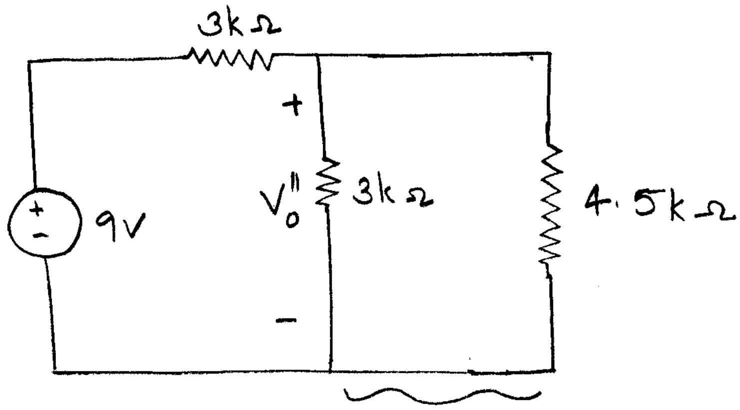
$$V_1 = 6 \times \frac{1.8}{4.8}$$

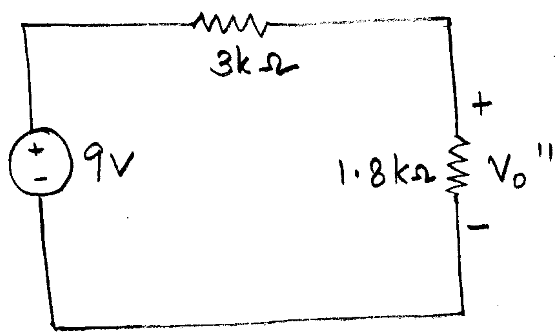
$$\therefore V_o' = 6 \times \frac{1.8}{4.8} \times \frac{1.5}{4.5} = 0.75V$$

Shorting 6V source









$$\therefore V_o'' = 9 \times \frac{1.8}{4.8} = 3.375\text{ V}$$
$$\approx 3.38\text{V}$$

Using Superposition

$$\boxed{\therefore V_o'' + V_o' = 3\text{V}}$$

5.11 Find I_o in the network in Fig. P5.11 using superposition.

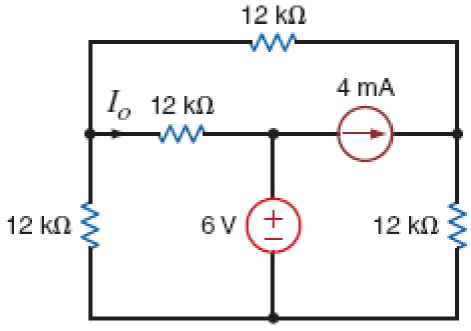
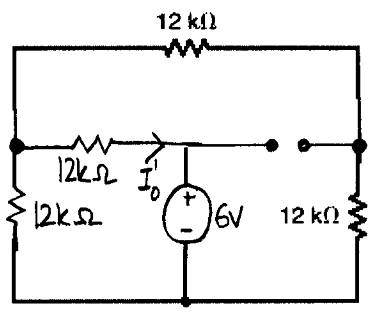
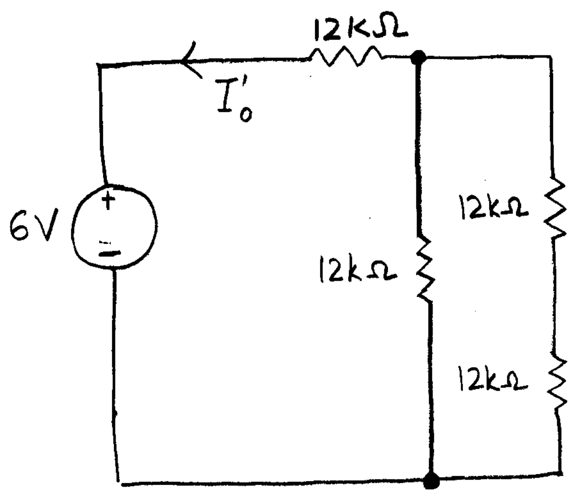


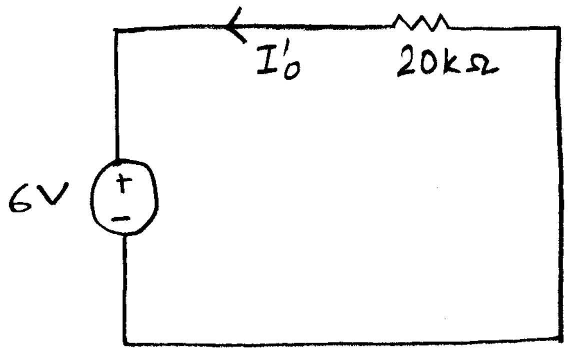
Figure P5.11

SOLUTION:

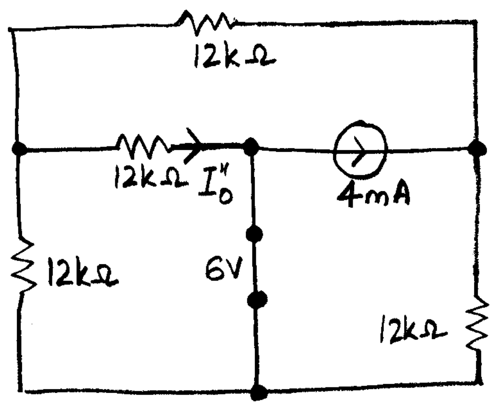


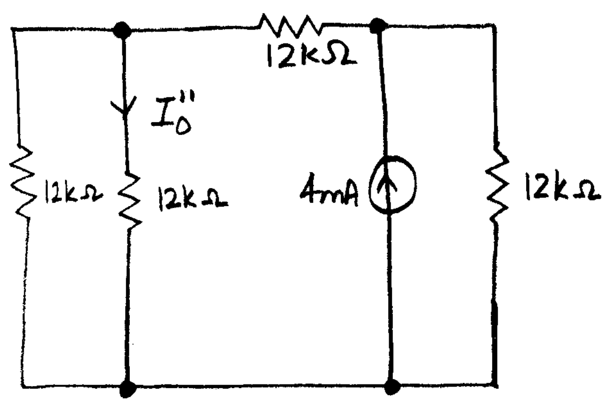


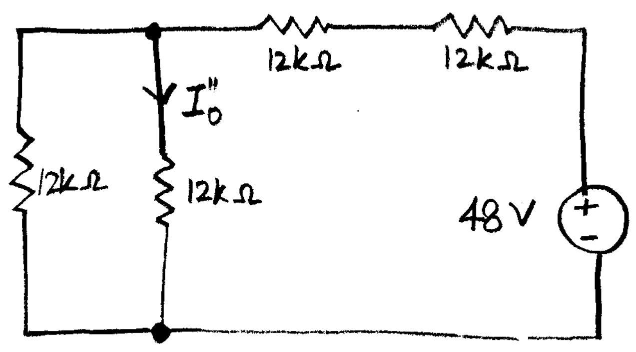
$$R_{eq} = \left(\left(12k + 12k\right) \| \; 12k\right) + 12k = 20k\Omega$$



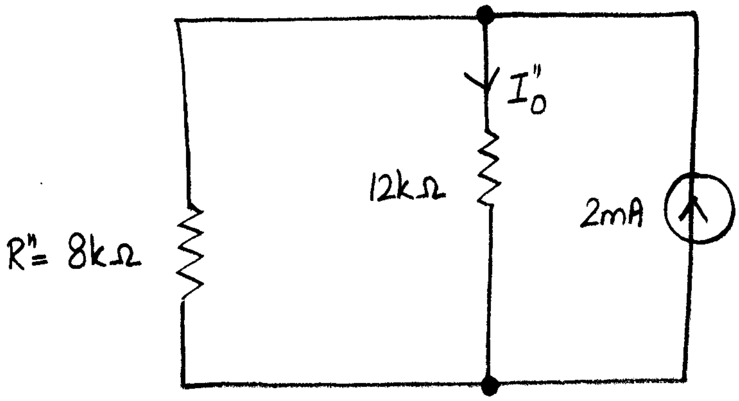
$$I_o' = \frac{-6}{20k} = -0.3mA$$







$$R'' = 12k \| 24k = 8k\Omega$$



$$I_0'' = \left(\frac{8k}{8k + 12k}\right) 2m = 0.8mA$$

$$I_0 = -0.3m + 0.8m = 0.5mA$$

5.12 Find I_o in the network in Fig. P5.12 using superposition.

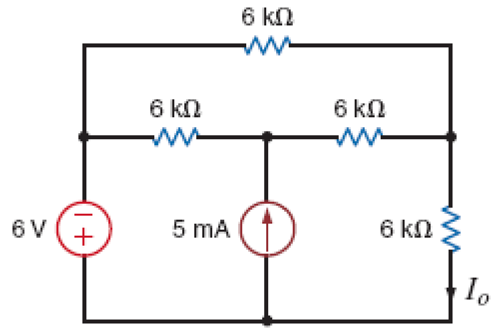
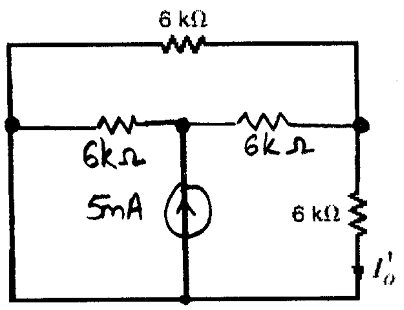
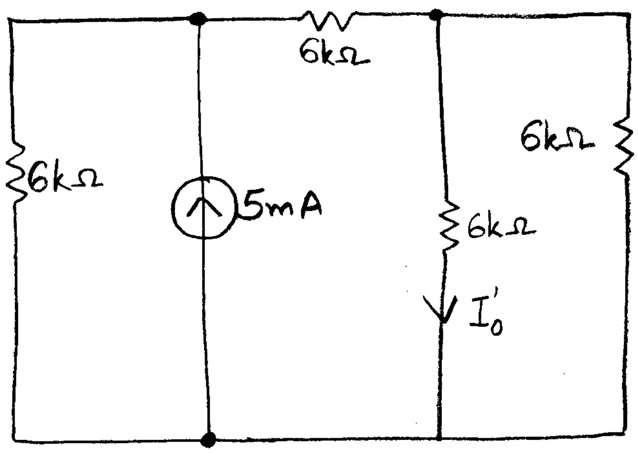


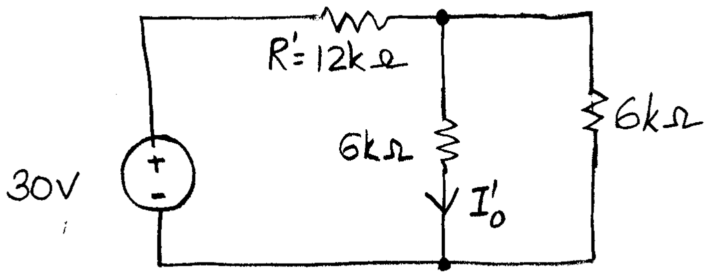
Figure P5.12

SOLUTION:

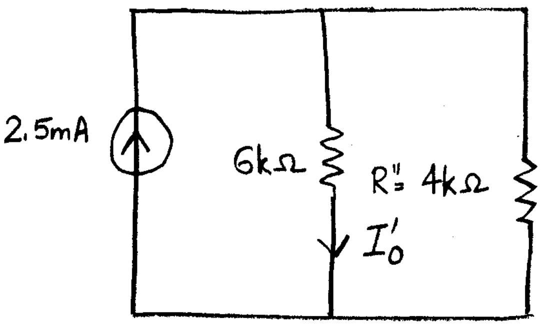




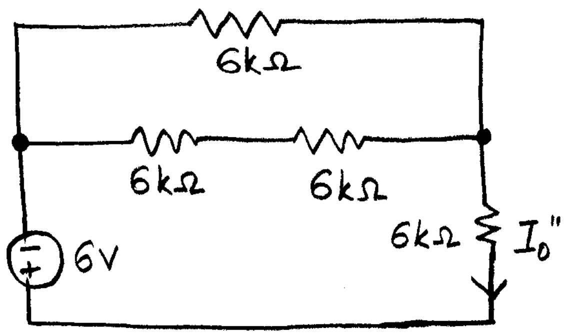
$R' = 6k + 6k = 12\,k\Omega$

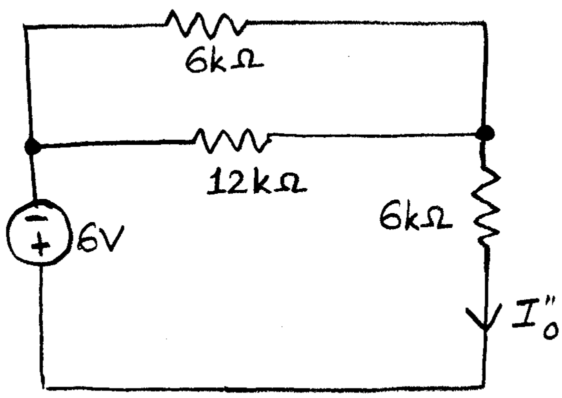


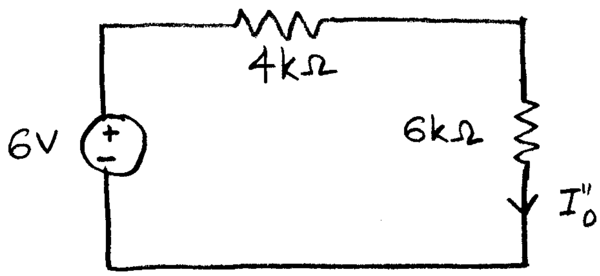
$$R'' = 6k \,||\, 12k = 4k\Omega$$



$$I_0' = \left(\frac{4k}{4k+6k}\right)(2.5m) = 1mA$$







$$I_0'' = \left(\frac{-6}{4k + 6k}\right) = -0.6mA$$

$$I_0 = 1m - 0.6m = 0.4mA$$

5.13 Find I_A in the network in Fig. P5.13 using superposition.

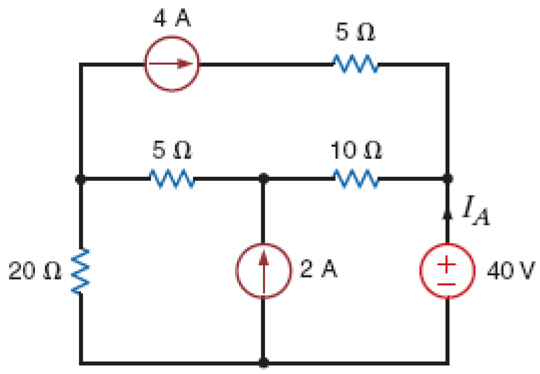
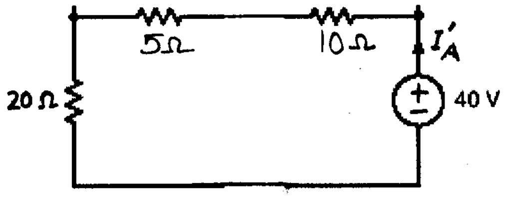
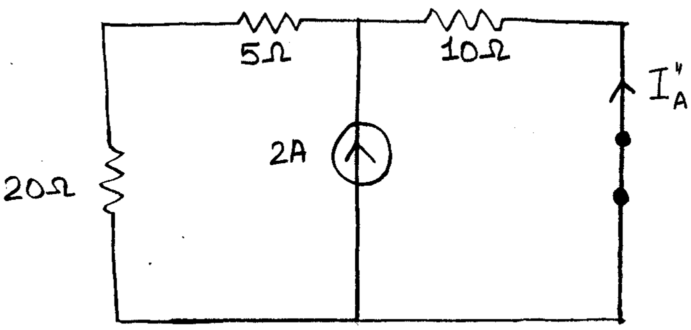


Figure P5.13

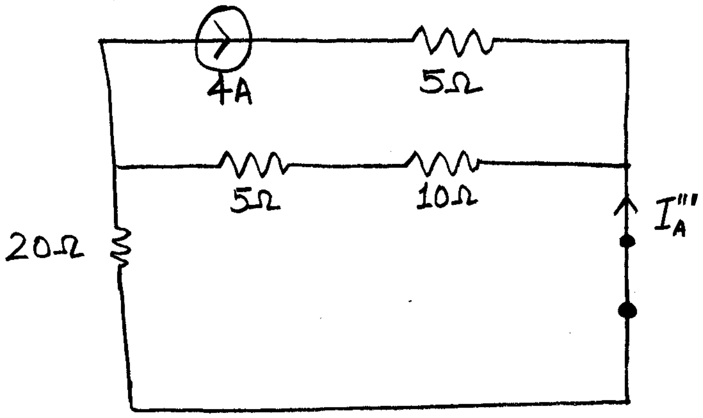
SOLUTION:



$$I'_A = \left(\frac{40}{20+5+10}\right) = \frac{8}{7}\ A$$



$$I''_A = \left(\frac{5+20}{20+5+10}\right)(-2) = -\frac{10}{7}\ A$$



$$I_A''' = \left(\frac{5+10}{5+10+20}\right)(-4) = -\frac{12}{7}\,A$$

$$I_A = \frac{8}{7} - \frac{10}{7} - \frac{12}{7} = -2A$$

5.14 Find I_A in the network in Fig. P5.14 using superposition.

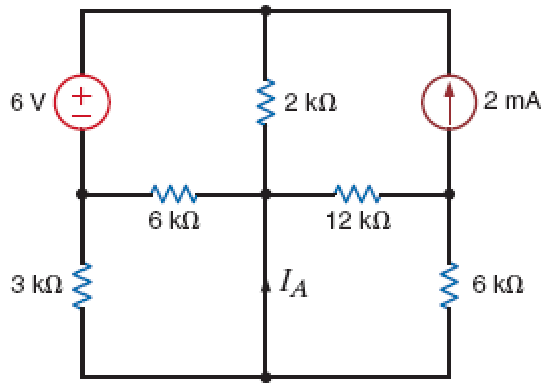
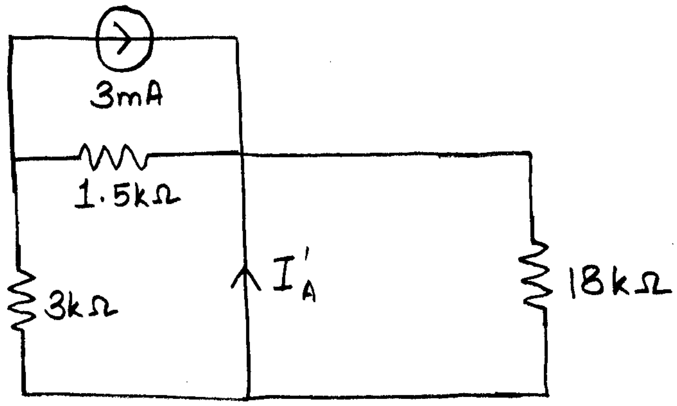
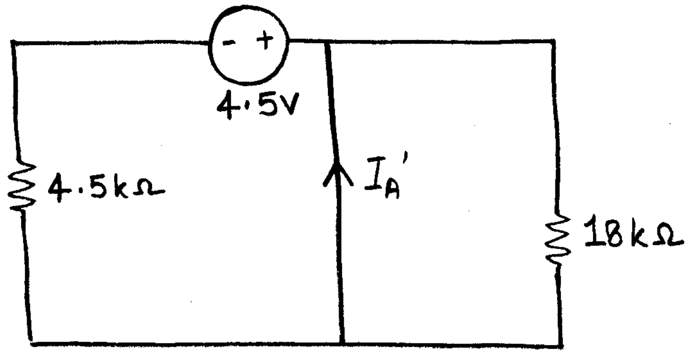
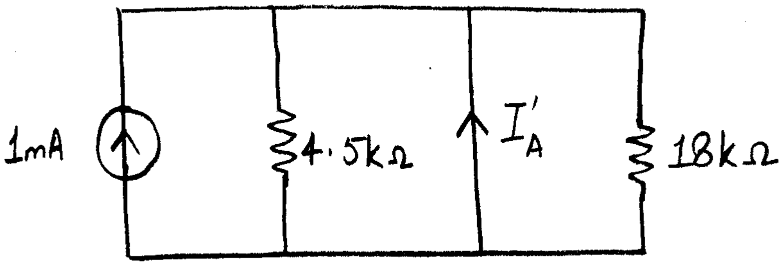


Figure P5.14

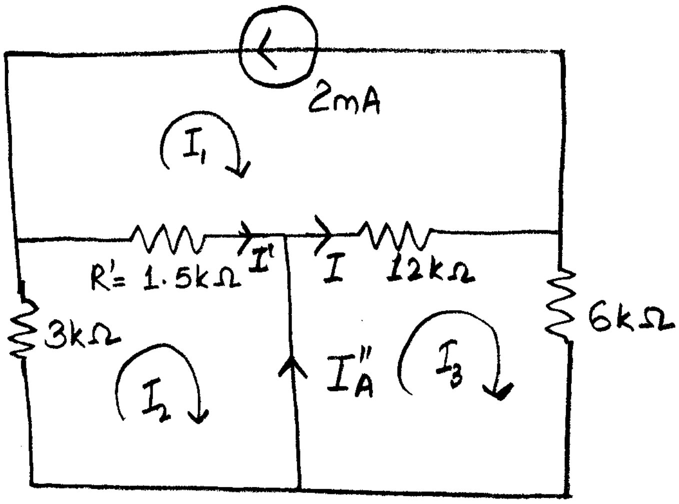
SOLUTION:







$I_A' = -1mA$



$$I_1 = -2mA$$
$$I_2 + I_A'' = I_3$$

$$I_A'' = I_3 - I_2$$
$$I_2 = I_1 + I'$$
$$I' = I_2 - I_1$$
$$I_1 + I = I_3$$

$$I = I_3 - I_1$$

KVL outer loop:

$$3I_2 + 1.5I' + 12kI + 6kI_3 = 0$$
$$4.5I_2 + 18kI_3 = -27$$

KVL right loop:

$$12kI + 6kI_3 = 0$$
$$18kI_3 = -24$$
$$I_3 = -1.33mA$$

$$4.5I_2 + 18k(-1.33m) = -27$$
$$I_2 = -0.667mA$$
$$I_A'' = -1.33m + 0.667m$$
$$= -0.667mA$$
$$I_A = -1m - 0.667m$$
$$= -1.667mA$$

5.15 Find V_o in the circuit in Fig. P5.15 using superposition.

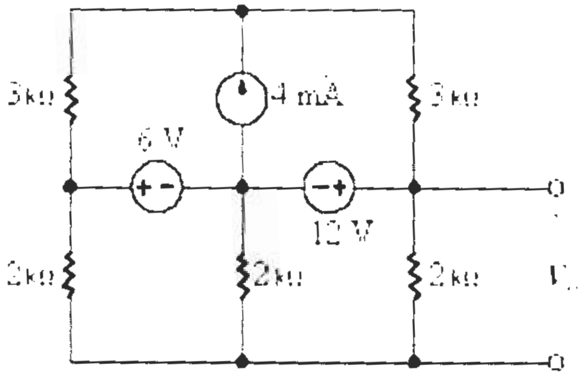
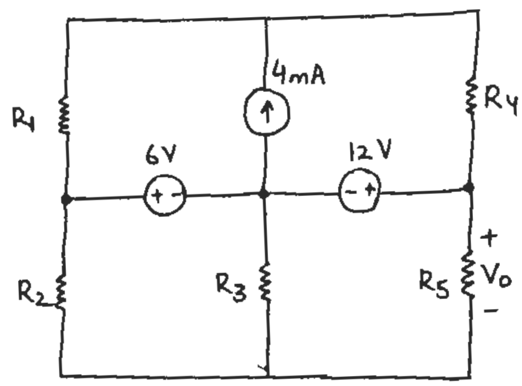
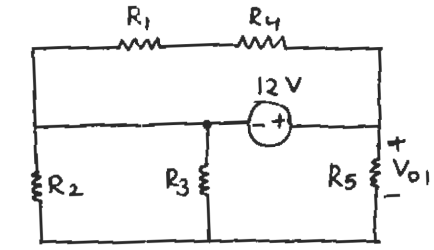


Figure P5.15

Solution: 5.15

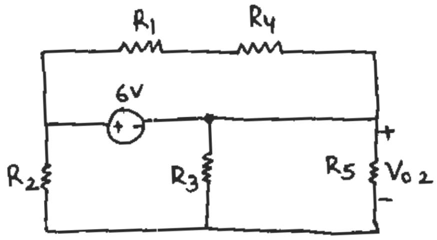


$R_1 = R_4 = 3k\Omega$, $R_2 = R_3 = R_5 = 2k\Omega$



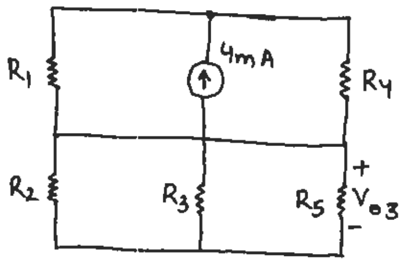
$R_A = R_2 \| R_3 = 1\ k\Omega$

$$V_{o1} = 12 \cdot \frac{R_5}{R_A + R_5} = 8\ V$$



$R_B = R_3 \| R_5 = 1k\Omega$

$$V_{o2} = -6 \cdot \frac{R_B}{R_B + R_2} = -2\ V$$



$$V_{o3} = 0\text{ V}$$

$$V_o = V_{o1} + V_{o2} + V_{o3}$$

$$\boxed{V_o = 6\text{ V}}$$

5.16 Use superposition to find I_o in the network in Fig. P5.16.

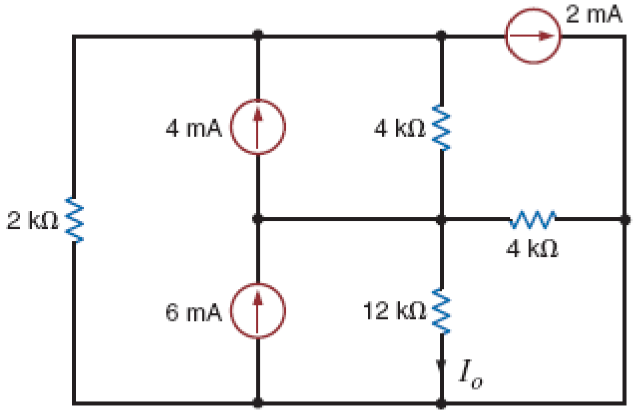
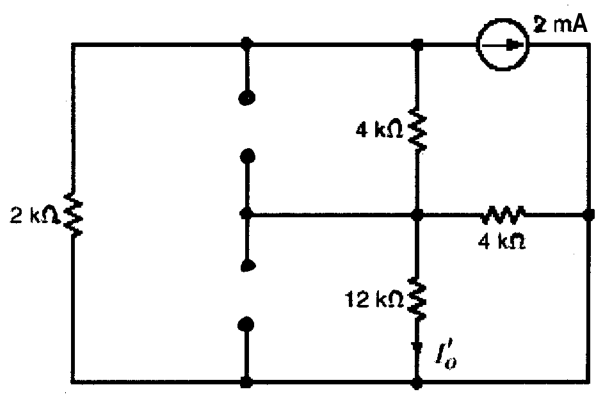
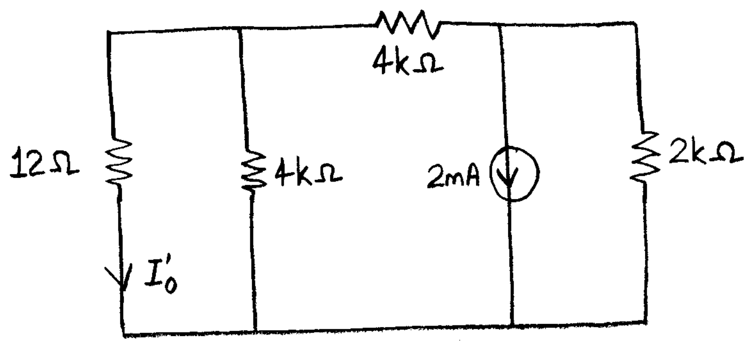
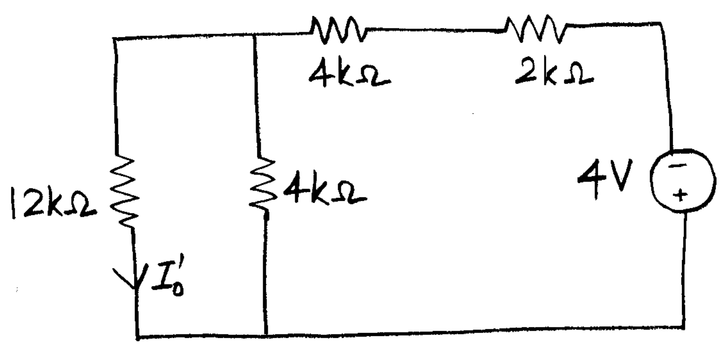


Figure P5.16

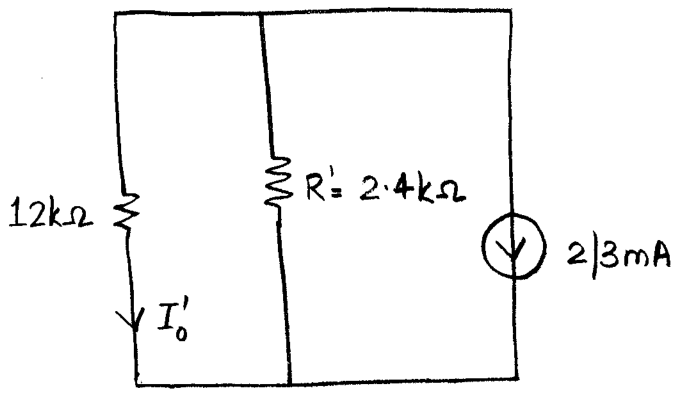
SOLUTION:



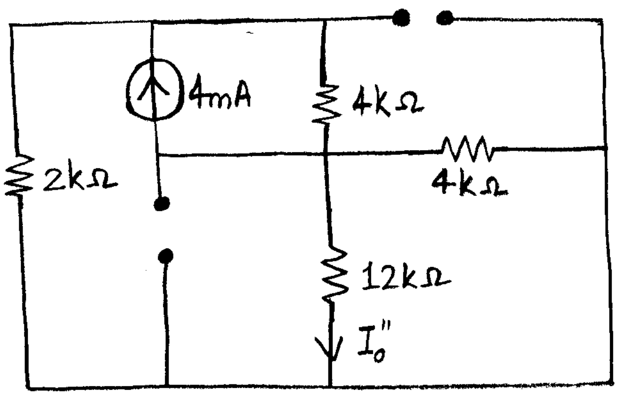


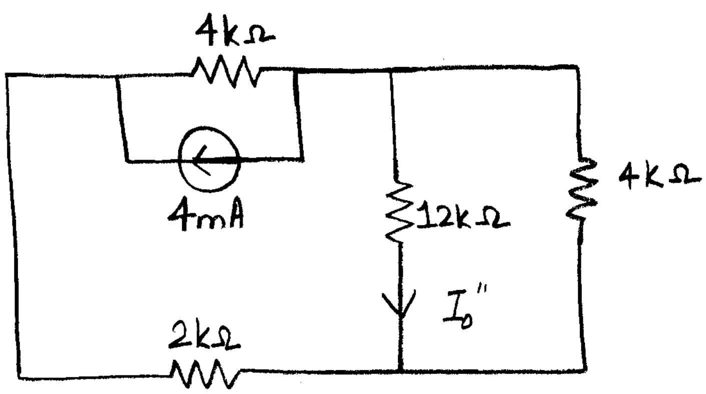


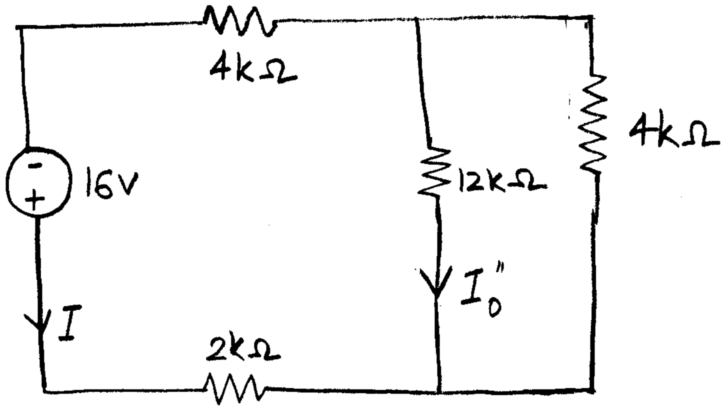
$$R' = 6k \| 4k = 2.4k\Omega$$



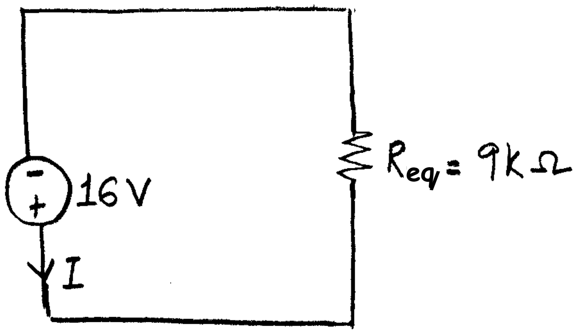
$$I_0' = \left(\frac{-2.4k}{2.4k + 12k}\right)\left(\frac{2}{3}m\right) = -0.111mA$$





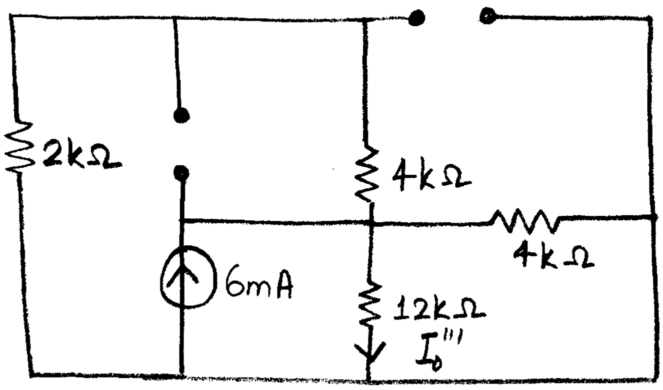


$$R_{eq} = 12k \,||\, 4k + 6k = 9k\Omega$$

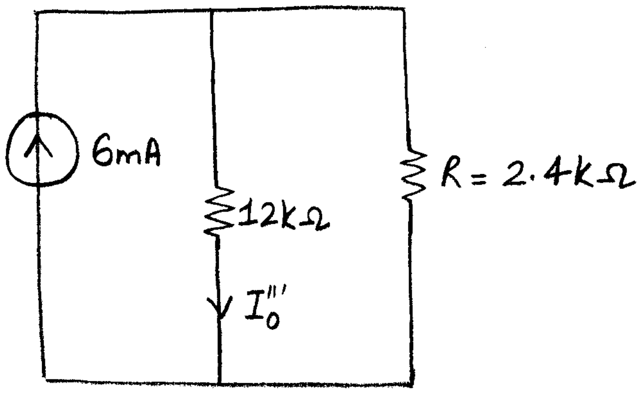


$$I = \frac{16}{9k} = 1.78mA$$

$$I_0'' = \left(\frac{4k}{12k + 4k}\right)(-1.78m) = -0.445mA$$



$$R = 6k \,||\, 4k = 2.4k\Omega$$



$$I_0''' = \left(\frac{2.4k}{2.4k + 12k}\right)(6m) = 1mA$$

$$I_0 = -0.111m - 0.445m + 1m = 0.444mA$$

5.17 Find I_o in the circuit in Fig. P5.17 using superposition.

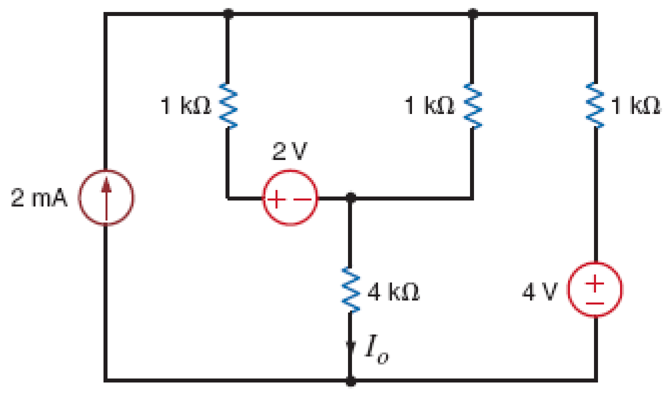
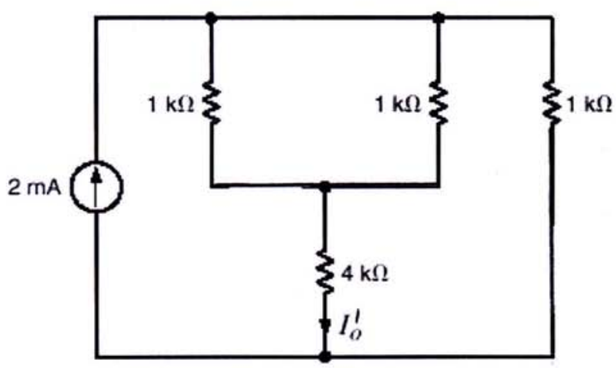
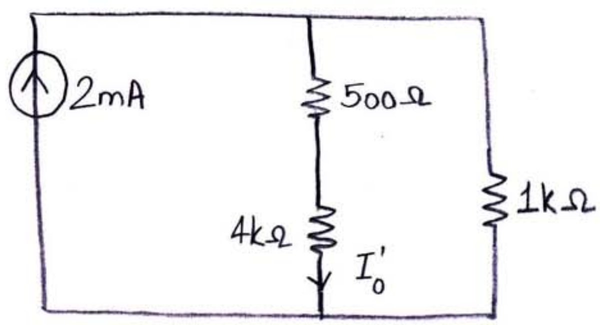


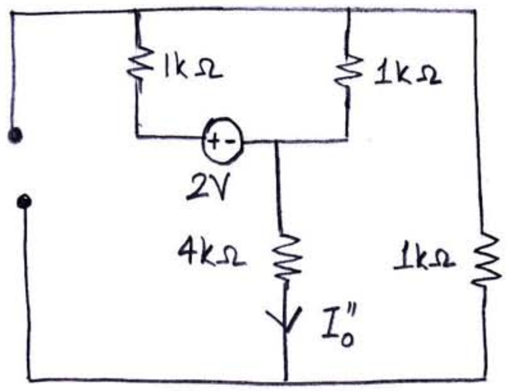
Figure P5.17

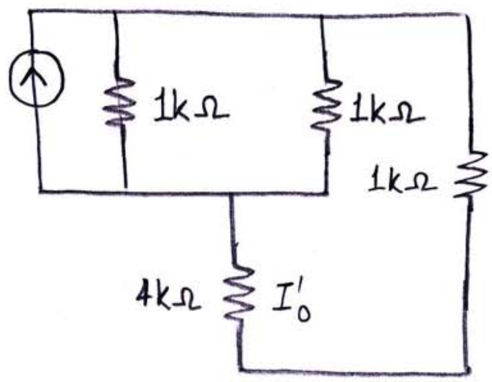
SOLUTION:

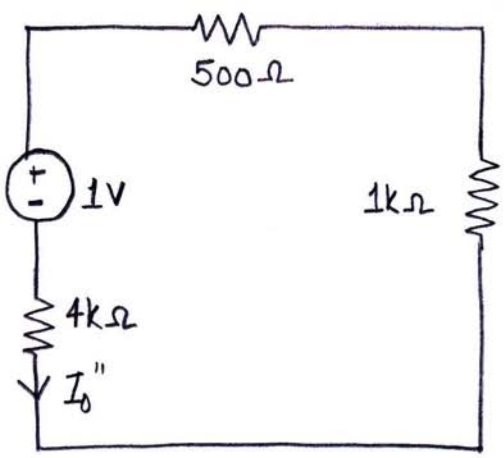




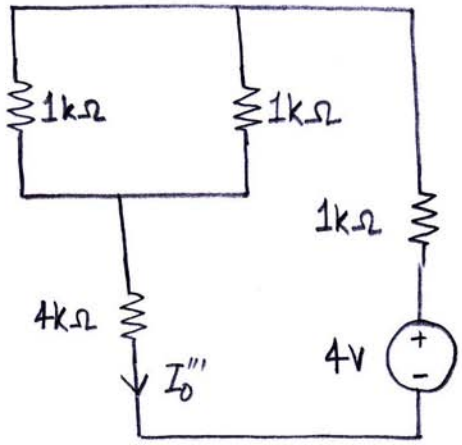
$$I_o' = \left(\frac{1k}{1k + 500 + 4k}\right)(2m) = 0.364 mA$$

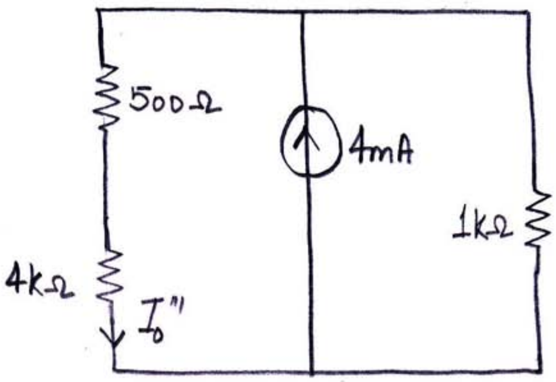






$$I_0'' = \frac{-1}{4k + 500 + 1k} = -0.182\text{mA}$$





$$I_o''' = \left(\frac{1k}{1k+500+4k}\right)(4m) = 0.727mA$$

$$I_o = 0.364m - 0.182m + 0.727m$$
$$= 0.909mA$$

5.18 Use superposition to find I_o in the circuit in Fig. P5.18.

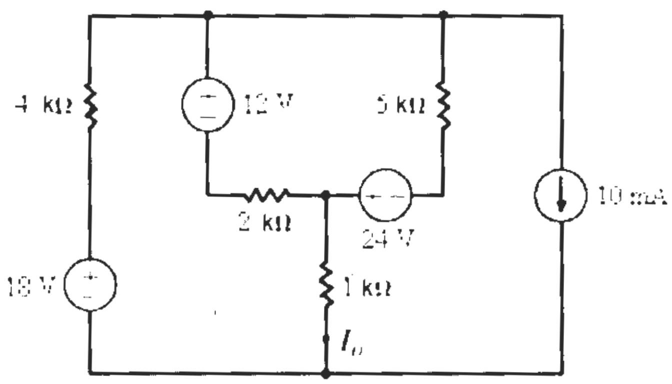
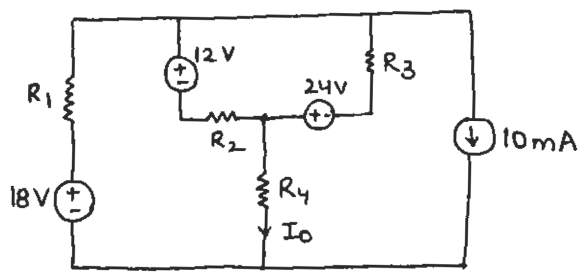
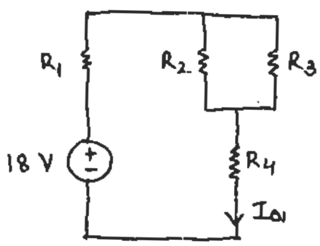


Figure P5.18

Solution: 5.18



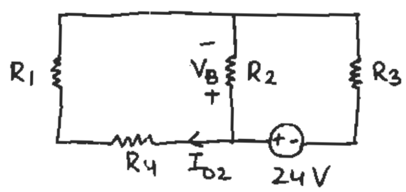
$R_1 = 4\,k\Omega$, $R_2 = 2\,k\Omega$, $R_3 = 5\,k\Omega$, $R_4 = 1\,k\Omega$



$$R_A = R_2 \| R_3 = 1.43\ k\Omega$$

$$I_{o1} = \frac{18}{R_1 + R_A + R_4}$$

$$I_{o1} = 2.80\ mA$$

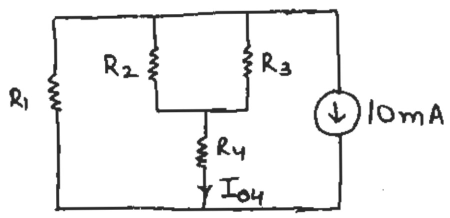


$$R_B = (R_1 + R_4) \| R_2 = 1.43\,k\Omega$$

$$V_B = 24 \cdot \frac{R_B}{R_B + R_3}$$

$$V_B = 5.34\ V$$

$$I_{o2} = \frac{V_B}{R_1 + R_4}, \quad I_{o2} = 1.07\ mA$$



$R_D = R_4 + (R_2 \| R_3) = 2.43\ k\Omega$

$I_{o4} = -10 \times 10^{-3} \cdot \dfrac{R_1}{R_1 + R_D}$

$= -6.22\ mA$

$I_o = I_{o1} + I_{o2} + I_{o3} + I_{o4}$

$\boxed{I_o = -3.68\ mA}$

5.19 Use superposition to find I_o in the circuit in Fig. P5.19.

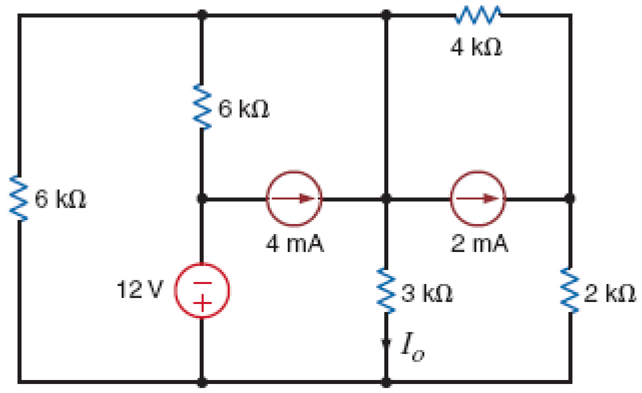
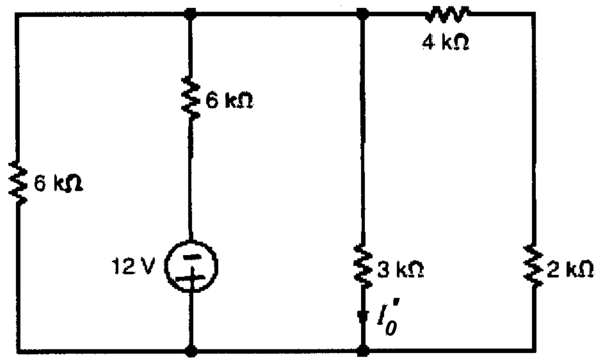
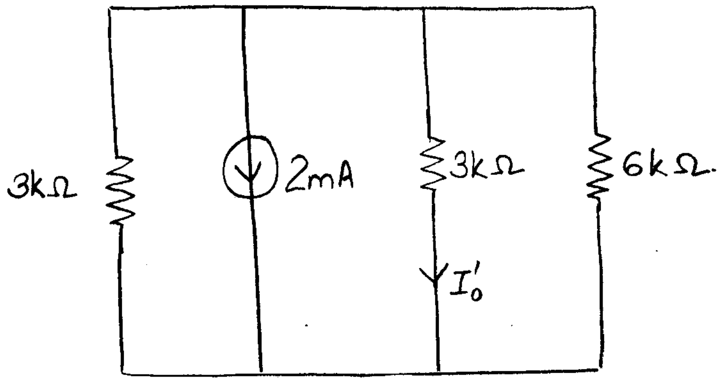


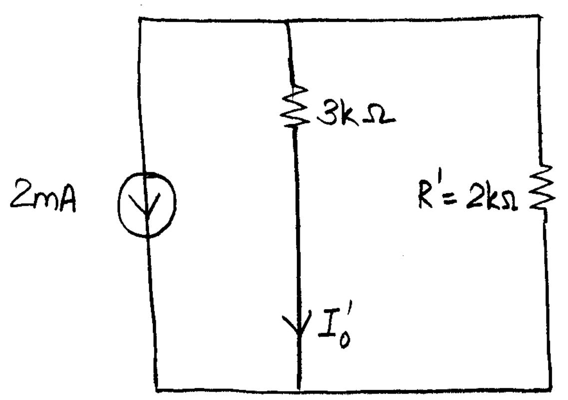
Figure P5.19

SOLUTION:

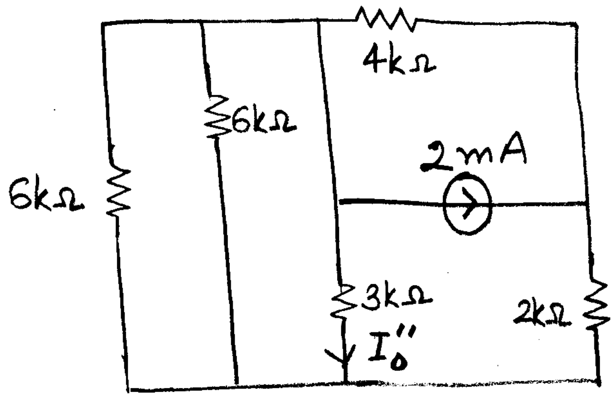


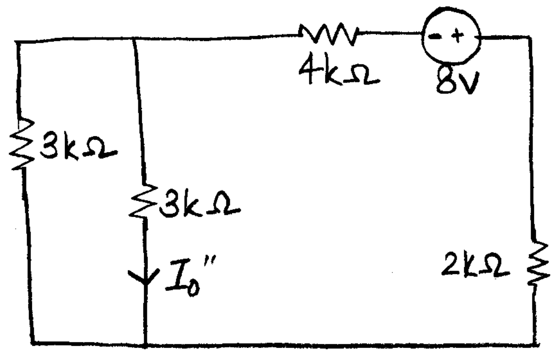


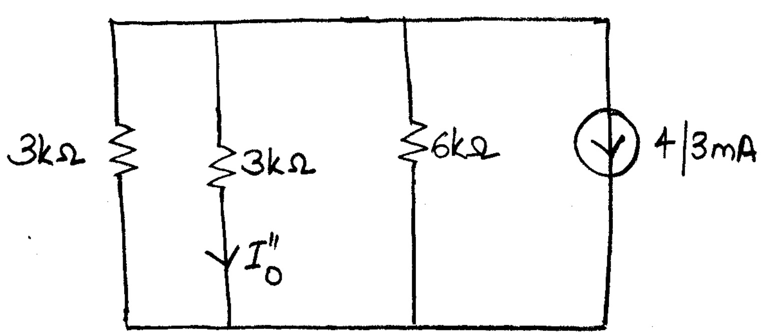
$R' = 6k \| 3K = 2K\Omega$

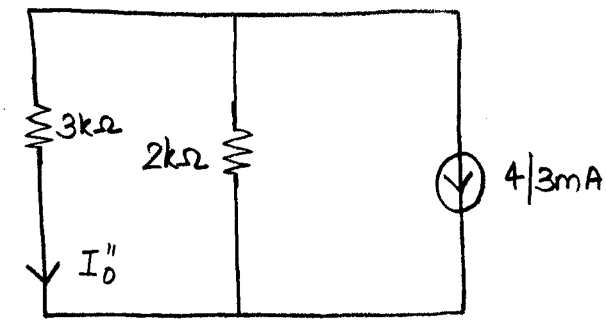


$$I_0' = \left(\frac{2k}{2k + 3k}\right)(-2m) = -0.8mA$$

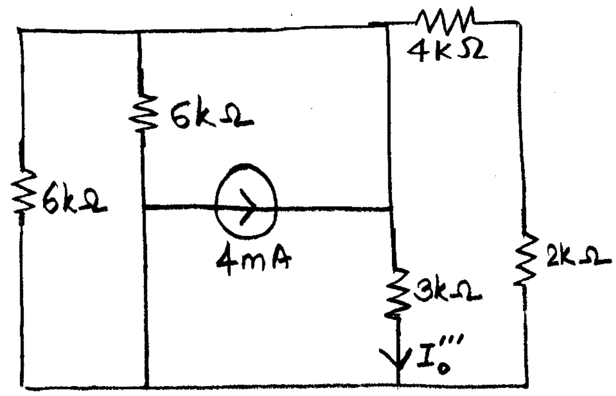


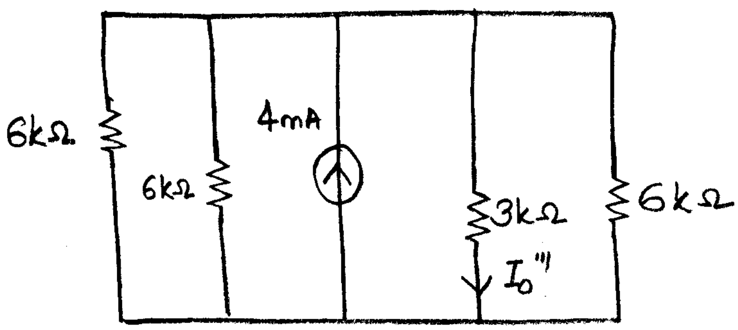




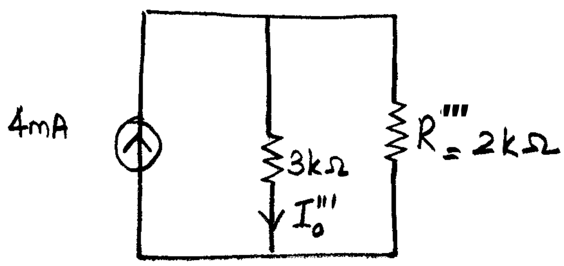


$$I_o'' = \left(\frac{2k}{2k+3k}\right)\left(-\frac{4}{3}m\right) = -\frac{8}{15}\ mA$$





$$R''' = 6k \| 6k \| 6\,K$$



$$I_0''' = \left(\frac{2k}{2k+3k}\right)(4m) = 1.6mA$$

$$I_0 = -0.8m - \frac{8}{15}m + 1.6m = 0.27mA$$

5.20 Use Thévenin's theorem to find V_o in the network in Fig. P5.20.

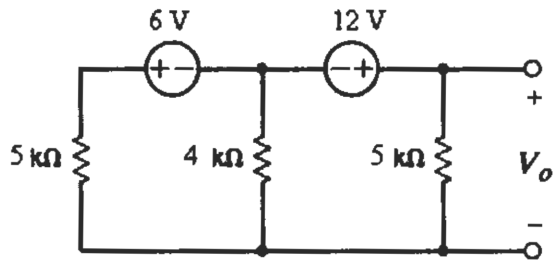
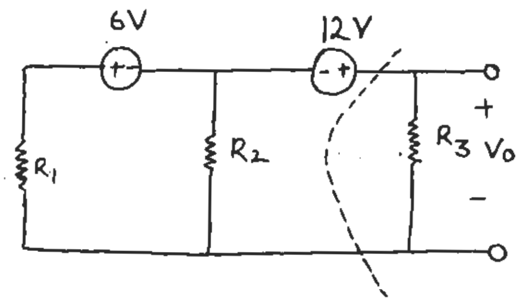
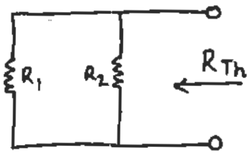


Figure P5.20

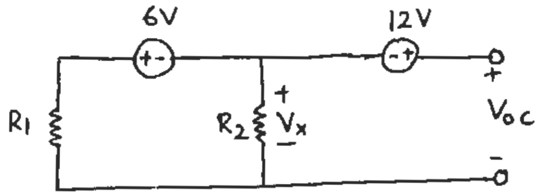
Solution: 5.20



$R_1 = 5\,k\Omega,\ R_2 = 4\,k\Omega,\ R_3 = 5\,k\Omega$



$$R_{Th} = R_1 \parallel R_2 = 5 \parallel 4 = \frac{20}{9} = 2.22\,k\Omega$$



$$V_x = (-6) \cdot \frac{R_2}{R_1 + R_2}$$

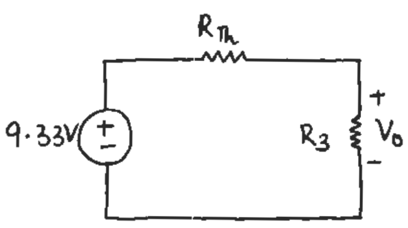
$$= (-6) \cdot \frac{4}{9}$$

$$= -\frac{8}{3} = -2.66\ V$$

$$V_{oc} = 12 + V_x$$

$$= 12 - \frac{8}{3}$$

$$= 9.33\ V$$



$$V_o = 9.33 \times \frac{R_3}{R_3 + R_{Th}}$$

$$= 9.33 \times \frac{5}{7.22}$$

$$\boxed{V_o = 6.46\ V}$$

5.21 Use Thévenin's theorem to find V_o in the network in Fig. P5.21

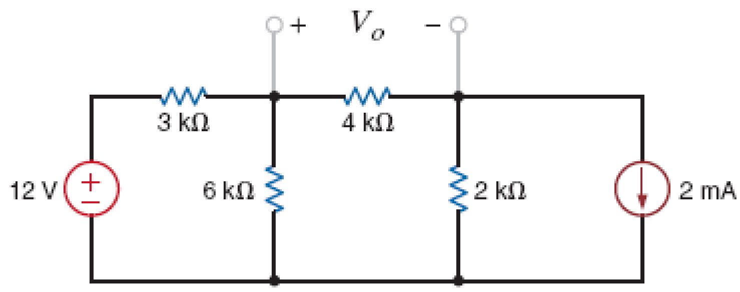
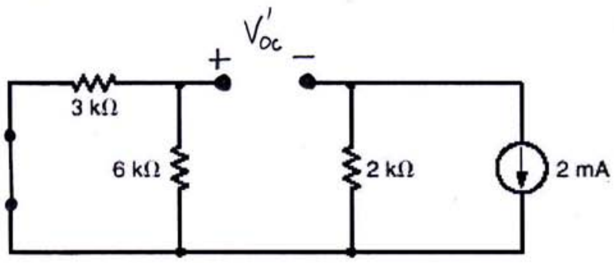
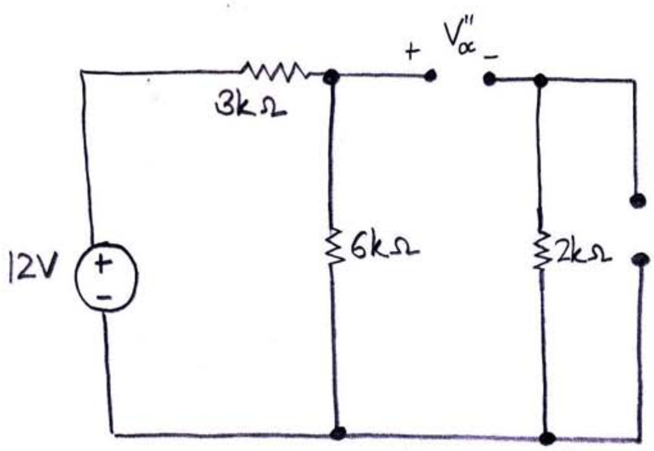


Figure P5.21

SOLUTION:

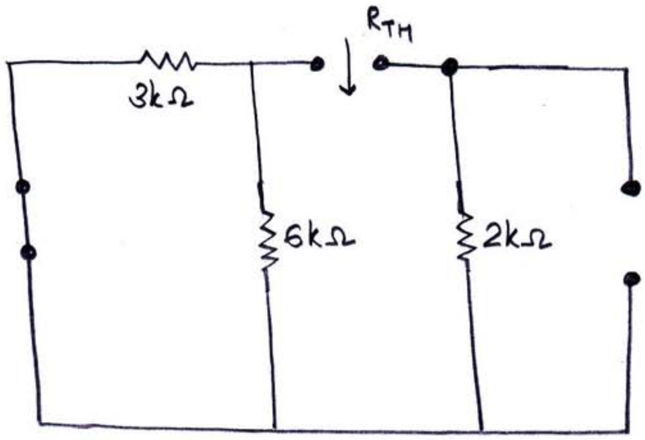


$$V'_{oc} = 2m(2k) = 4V$$

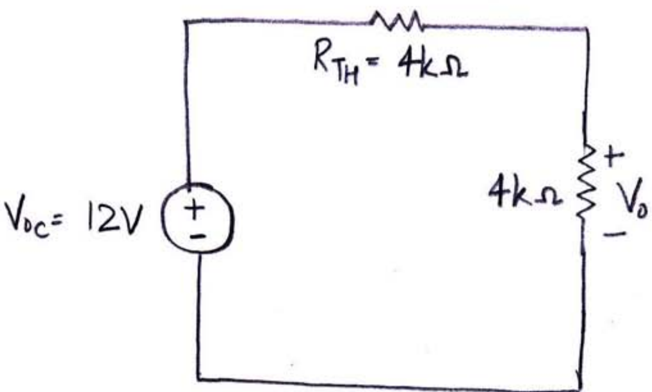


$$V''_{oc} = \left(\frac{6k}{3k + 6k}\right)(12) = 8V$$

$$V_{oc} = 4 + 8 = 12V$$



$$R_{TH} = (3k \,||\, 6k) + 2k = \frac{3k(6k)}{3k+6k} + 2k = 4k\Omega$$



$$V_o = \left(\frac{4k}{4k+4k}\right)(12) = 6V$$

5.22 Find I_o in the network in Fig. P5.22 using Thévenin's theorem.

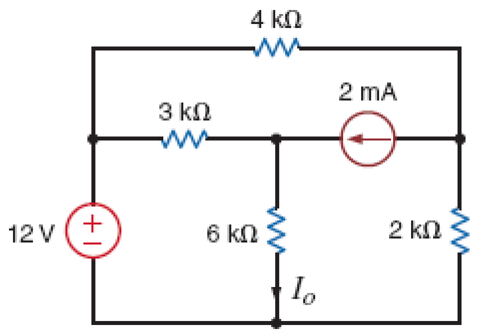
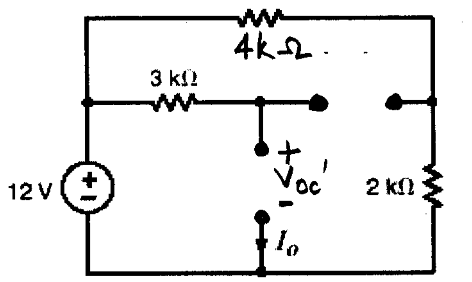
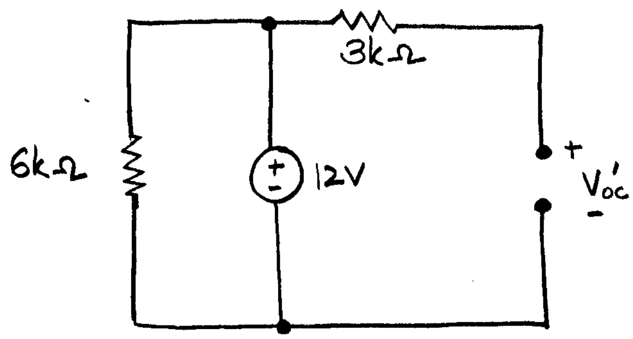


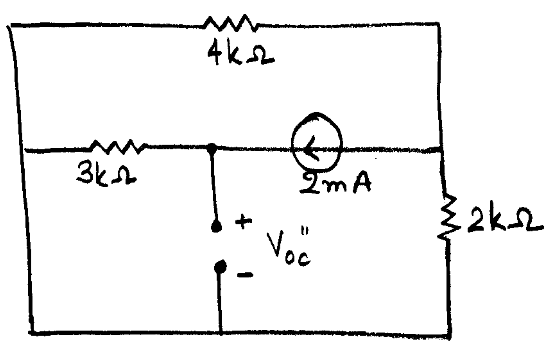
Figure P5.22

SOLUTION:



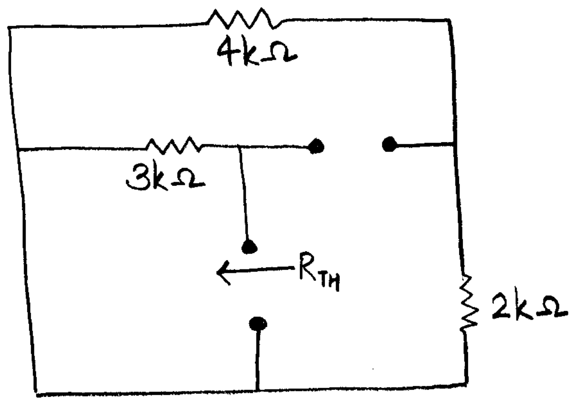


$$V'_{oc} = 12V$$

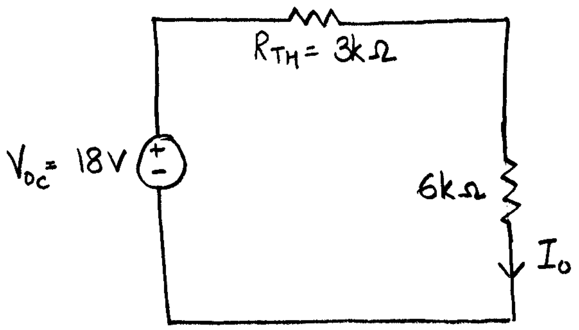


$$V_{oc}'' = 2m(3k) = 6V$$

$$V_{oc} = 12 + 6 = 18V$$



$$R_{TH} = 3k\Omega$$



$$I_o = \frac{18}{3k + 6k} = 2mA$$

5.23 Find V_o in the circuit in Fig. P5.23 using Thévenin's theorem.

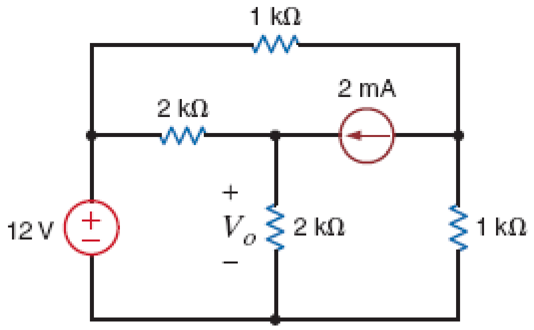
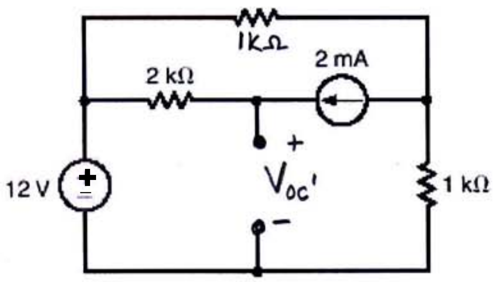
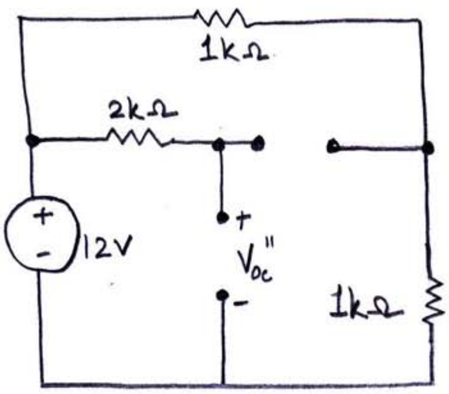


Figure P5.23

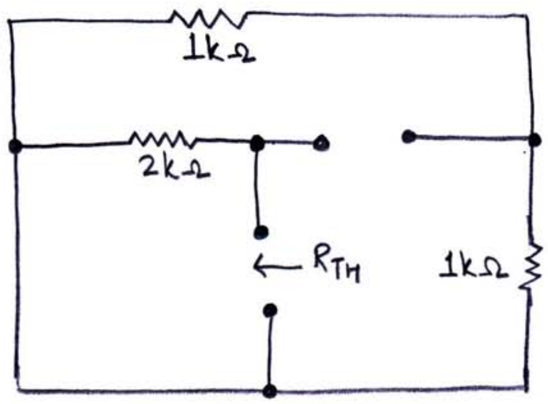
SOLUTION:



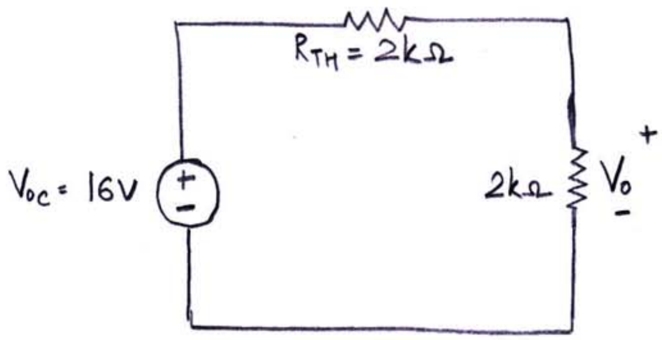
$$V_{oc}' = 2m(2k) = 4V$$



$$V_{oc}'' = 12V$$
$$V_{oc} = 4 + 12 = 16V$$



$R_{TH} = 2k\Omega$



$$V_o = \left(\frac{2k}{2k+2k}\right)(16) = 8V$$

5.24 Use Thévenin's theorem to find I_o in the network in Fig. P5.24.

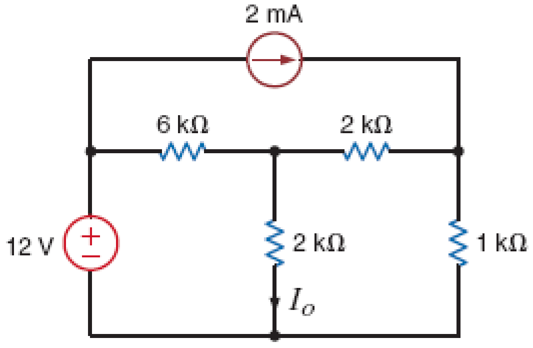
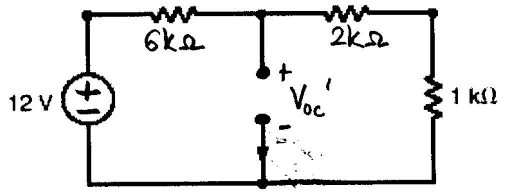
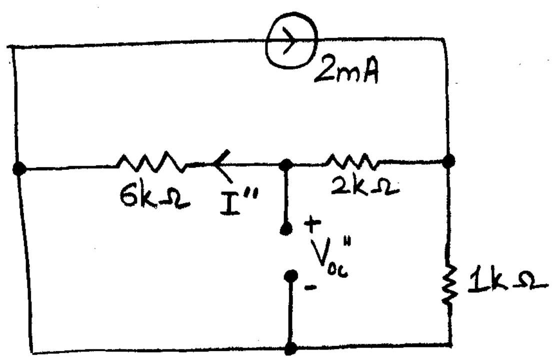


Figure P5.24

SOLUTION:



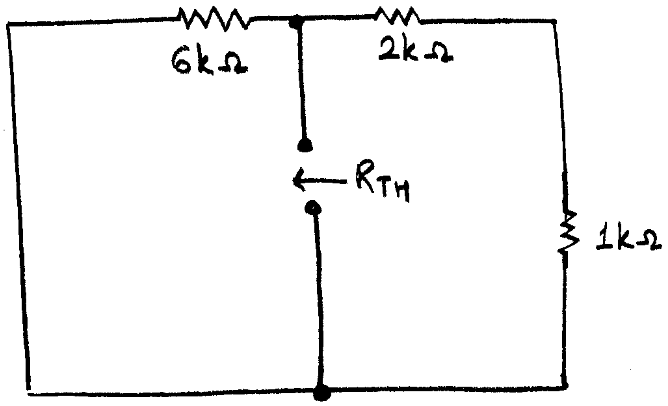
$$V_{oc}' = \left(\frac{3k}{3k+6k}\right)(12) = 4V$$



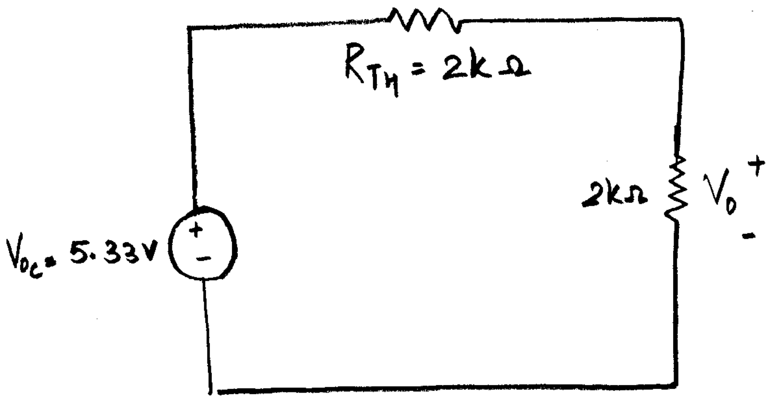
$$I'' = \left(\frac{1k}{1k+6k+2k}\right)(2m) = 0.222mA$$

$$V_{oc}'' = 6k(0.222m) = 1.333V$$

$$V_{oc} = 4 + 1.333 = 5.333V$$



$$R_{TH} = 6k \| 3k = 2k\Omega$$



$$I_o = \frac{5.333}{4k} = 1.333\,mA$$

5.25 Find V_o in the network in Fig. P5.25 using Thévenin's theorem.

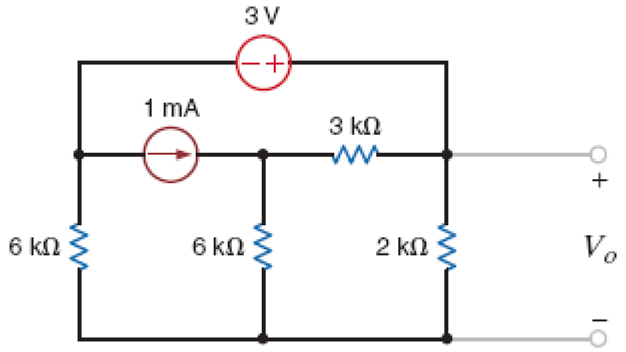
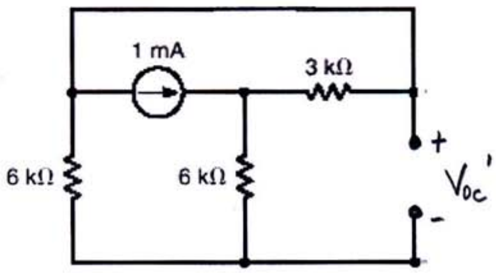
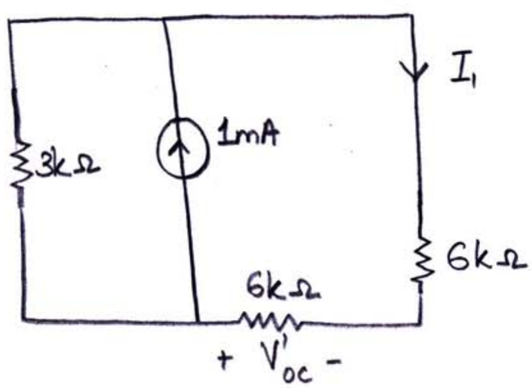


Figure P5.25

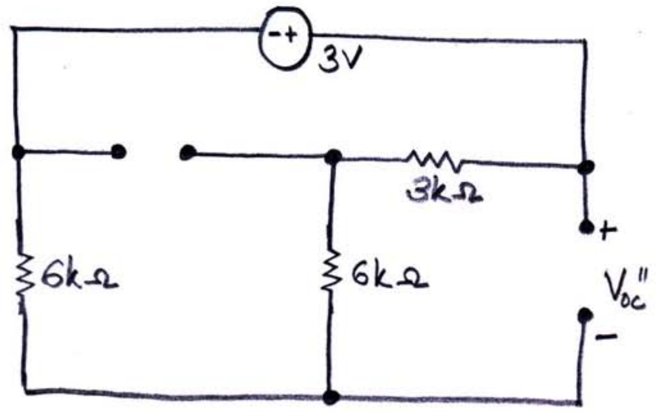
SOLUTION:





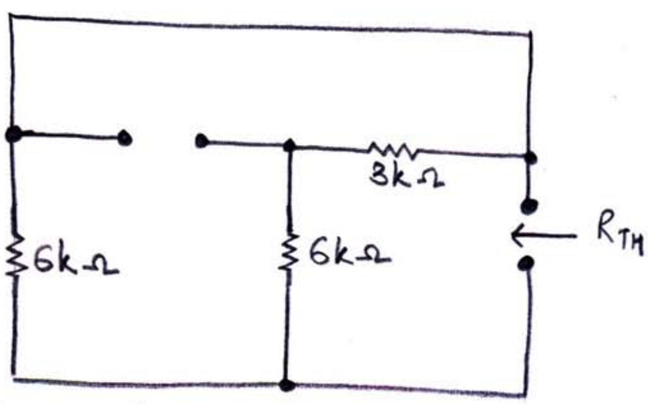
$$I_1 = \left(\frac{3k}{3k + 12k}\right)(1m) = 0.2mA$$

$$V_{oc}' = -0.2m(6k) = -1.2V$$

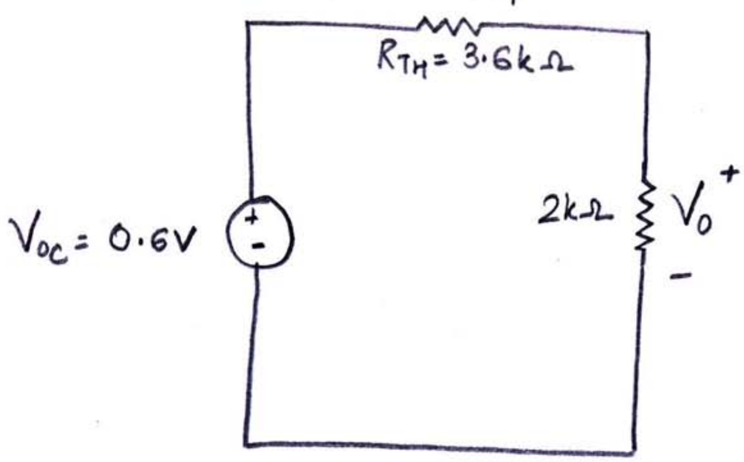


$$V''_{oc} = \left(\frac{9k}{9k+6k}\right)(3) = 1.8V$$

$$V_{oc} = -1.2 + 1.8 = 0.6V$$



$$R_{TH} = (6k+3k)\,||\,6k = 3.6k\Omega$$



$$V_o = \left(\frac{2k}{2k + 3.6k} \right)(0.6) = 0.21V$$

5.26 Find I_o in the circuit in Fig. P5.26 using Thévenin's theorem.

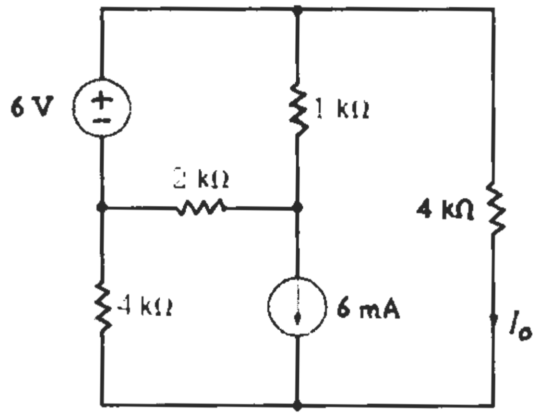
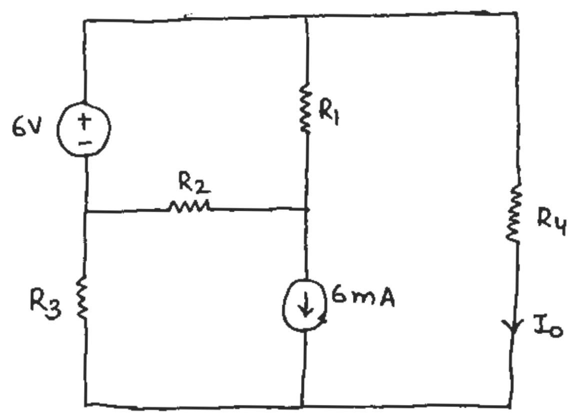
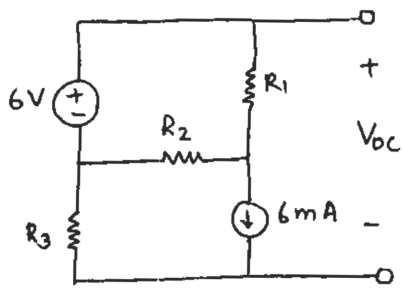


Figure P5.26

Solution: 5.26

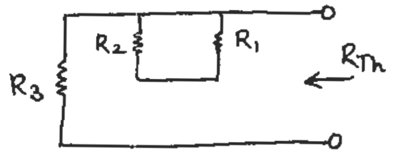


$R_1 = 1k\Omega$, $R_2 = 2k\Omega$, $R_3 = R_4 = 4k\Omega$

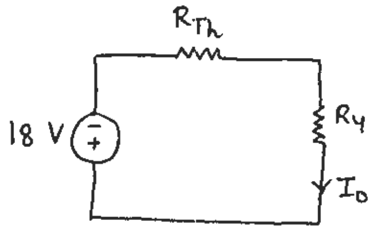


$$-6 + V_{oc} + 6\times10^{-3} R_3 = 0$$

$$\Rightarrow \quad V_{oc} = -18 \text{ V}$$



$$R_{Th} = R_3 = 4k\Omega$$



$$I_o = \frac{-18}{R_4 + R_{Th}}$$

$$\boxed{I_o = -2.25\ mA}$$

5.27 Find I_o in the network in Fig. P5.27 using Thévenin's theorem.

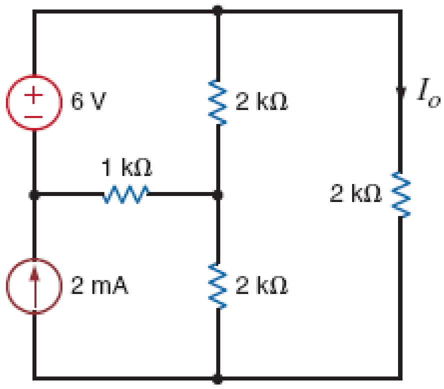
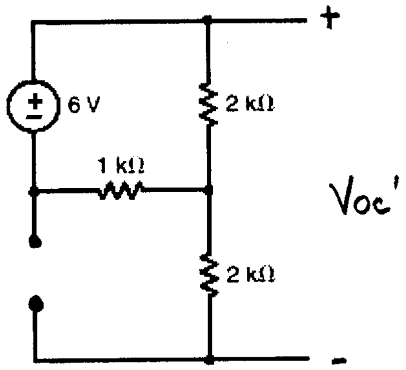
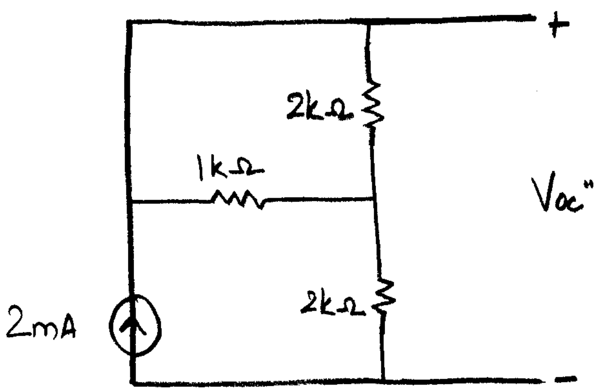


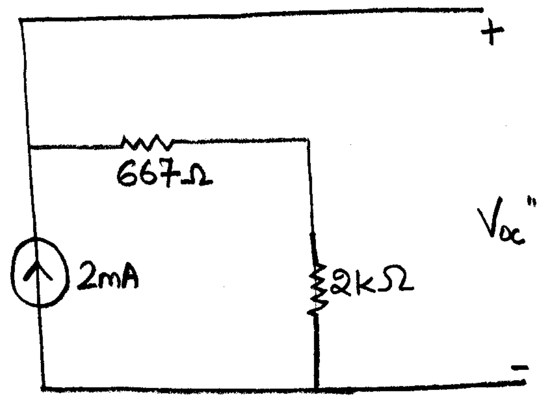
Figure P5.27

SOLUTION:



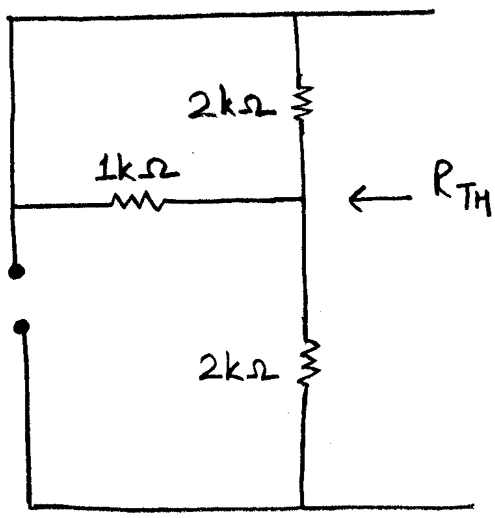
$$V_{oc}' = \left(\frac{2k}{2k + 1k}\right)(6) = 4V$$



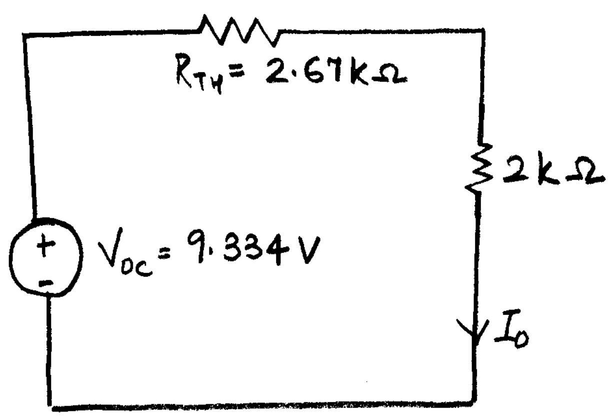


$$V''_{oc} = 2m(667 + 2k) = 5.334\text{V}$$

$$V_{oc} = 4 + 5.334 = 9.334\text{V}$$



$$R_{TH} = (1k \| 2k) + 2k = 2.67\text{k}\Omega$$



$$I_o = \frac{9.334}{2.67k + 2k} = 2\text{mA}$$

5.28 Find I_o in the network in Fig. P5.28 using Thévenin's theorem.

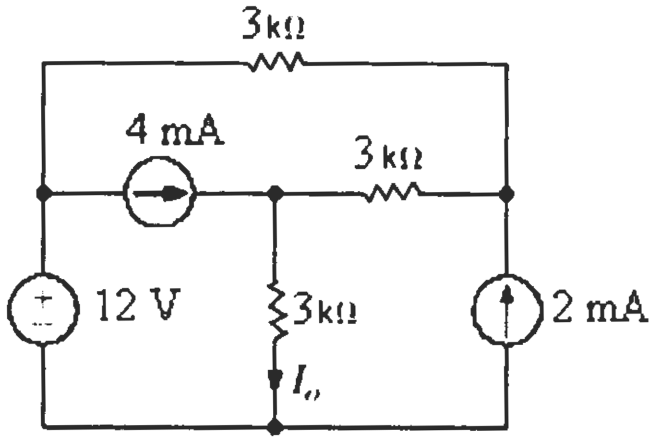
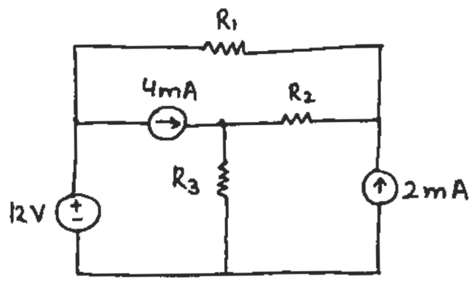


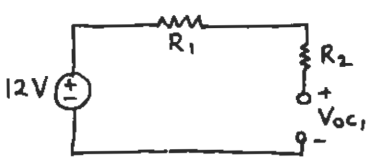
Figure P5.28

Solution: 5.28

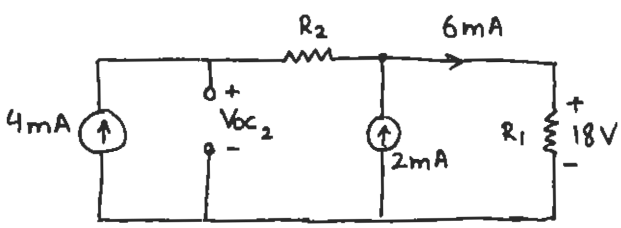


$R_1 = R_2 = R_3 = 3k\Omega$

By Superposition



$V_{oc_1} = 12\,V$

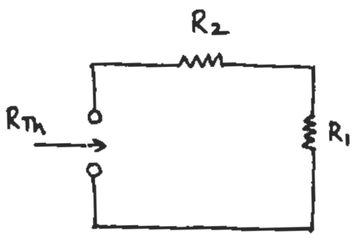


$V_{oc_2} = 4\times10^{-3} R_2 + 6\times10^{-3} R_1$

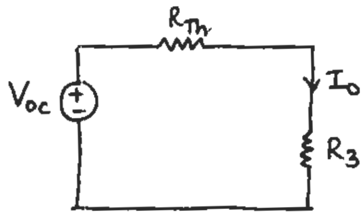
$V_{oc_2} = 30\ V$

$V_{oc} = V_{oc_1} + V_{oc_2}$

$V_{oc} = 42.0\ V$



$$R_{Th} = R_1 + R_2 = 6k\Omega$$



$$I_o = \frac{V_{oc}}{R_3 + R_{Th}}$$

$$\boxed{I_o = 4.67 \text{ mA}}$$

5.29 Find I_o in the network in Fig. P5.29 using Thévenin's theorem.

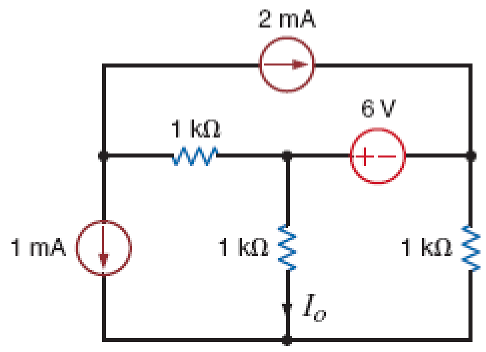
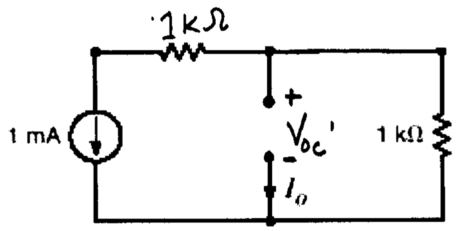
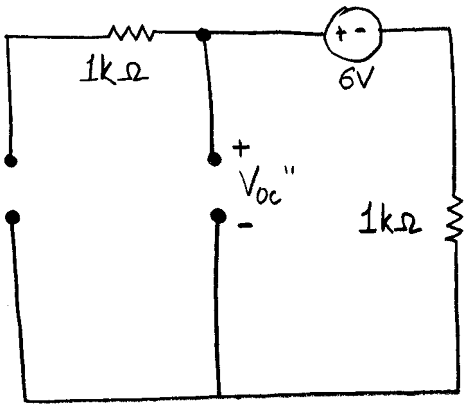


Figure P5.29

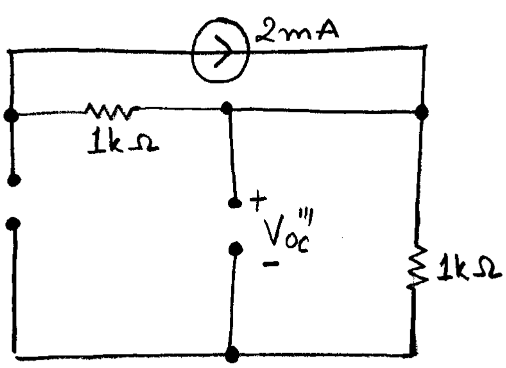
SOLUTION:



$$V_{oc}' = 1k(-1m) = -1V$$

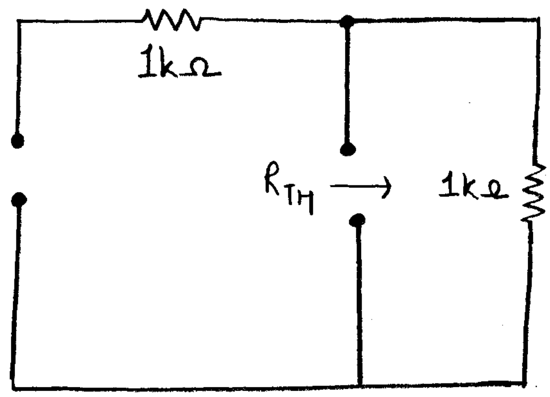


$$V_{oc}'' = 6V$$

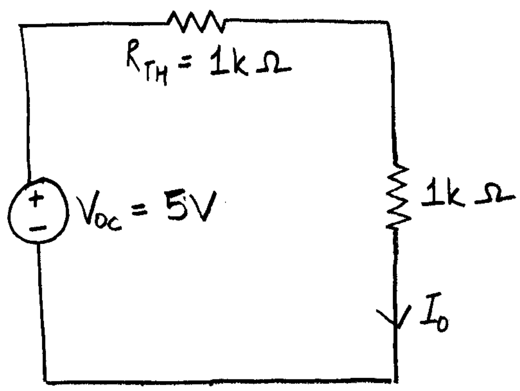


$$V''_{oc} = 0 \text{ Volts}$$

$$V_{oc} = -1 + 6 + 0 = 5\text{V}$$



$$R_{TH} = 1\text{k}\Omega$$



$$I_o = \frac{5}{2\text{k}} = 2.5\text{mA}$$

5.30 Find V_o in the Fig. P5.30 using Thévenin's theorem.

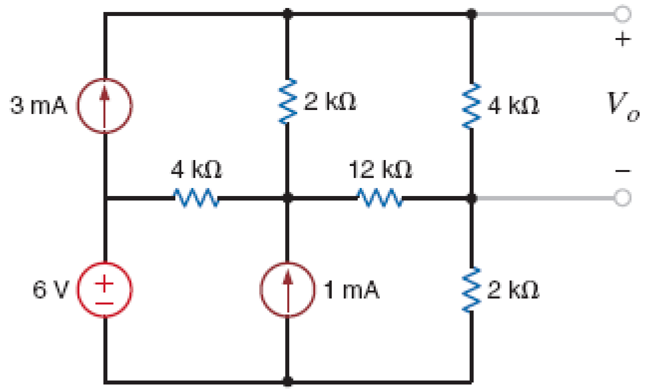
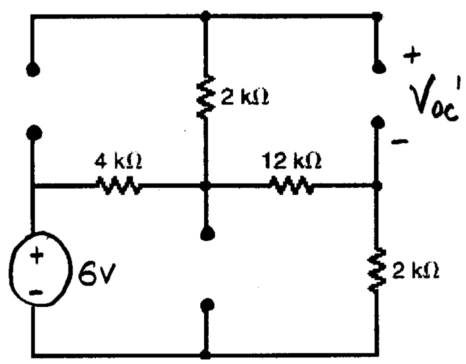
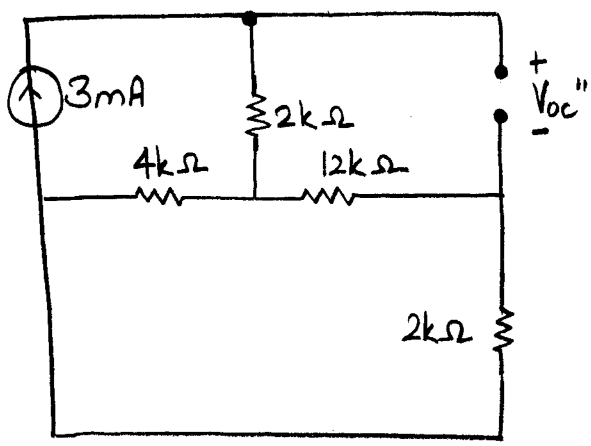


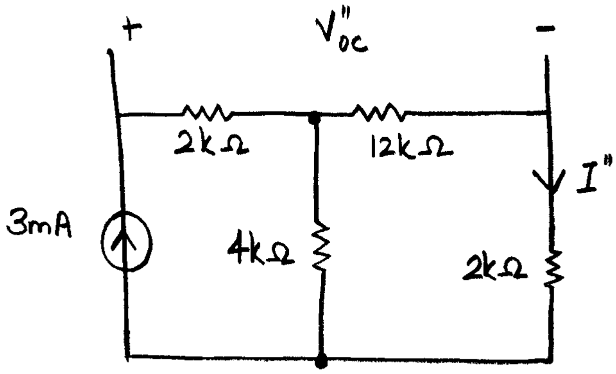
Figure P5.30

SOLUTION:



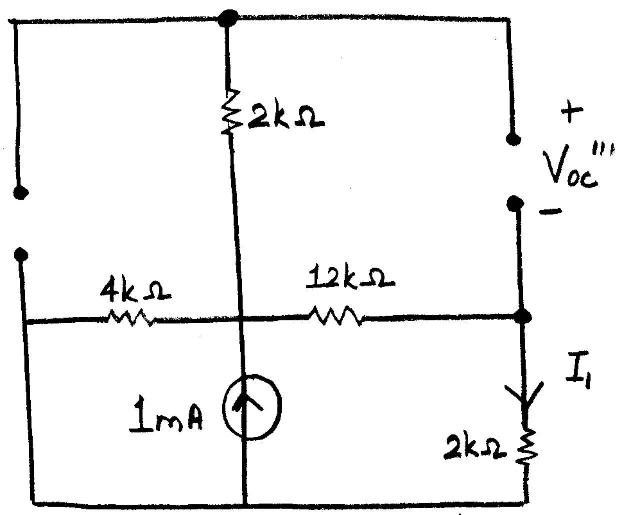
$$V_{oc}' = \left(\frac{12k}{4k+12k+2k}\right)(6) = 4V$$





$$I'' = \left(\frac{4k}{4k+12k+2k}\right)(3m) = 0.67mA$$

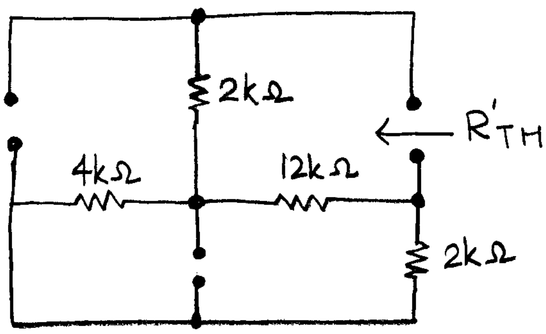
$$V''_{oc} = 2k(3m) + 12k(0.67m) = 14V$$

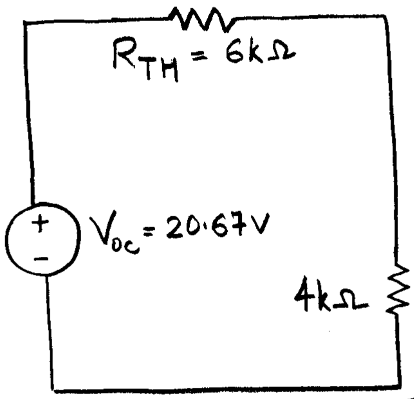


$$I_1 = \left(\frac{4k}{4k+12k+2k}\right)(1m) = 0.222mA$$

$$V'''_{oc} = 12k(0.222m) = 2.67V$$

$$V_{oc} = 4 + 14 + 2.67 = 20.67V$$





$$R_{TH} = \left[(2k + 4k) \| 12k\right] + 2k = 6k\Omega$$

$$V_o = \left(\frac{4k}{4k + 6k}\right)(20.67) = 8.27V$$

5.31 Use Thévenin's theorem to find V_o in the circuit in Fig. P5.31

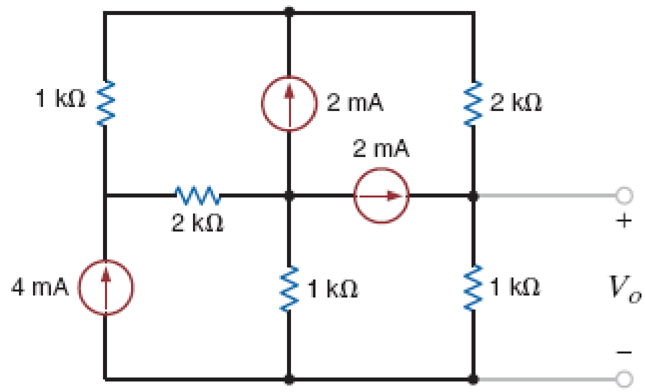
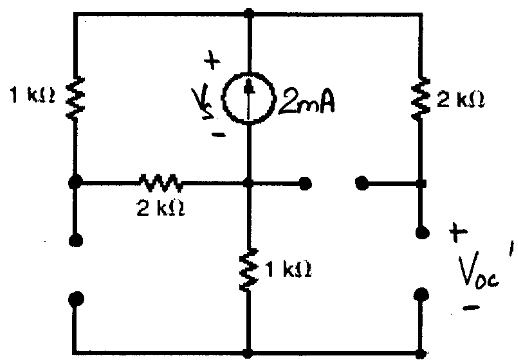


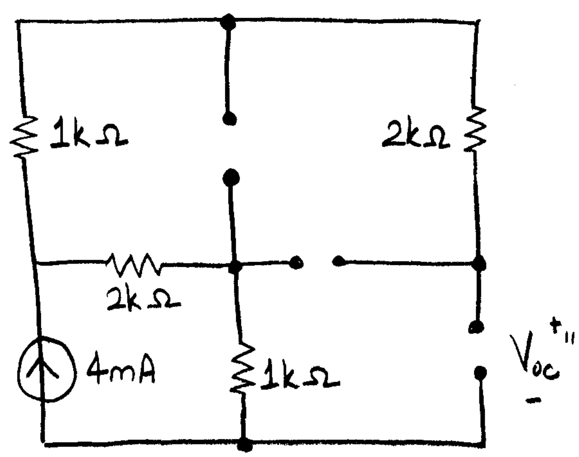
Figure P5.31

SOLUTION:

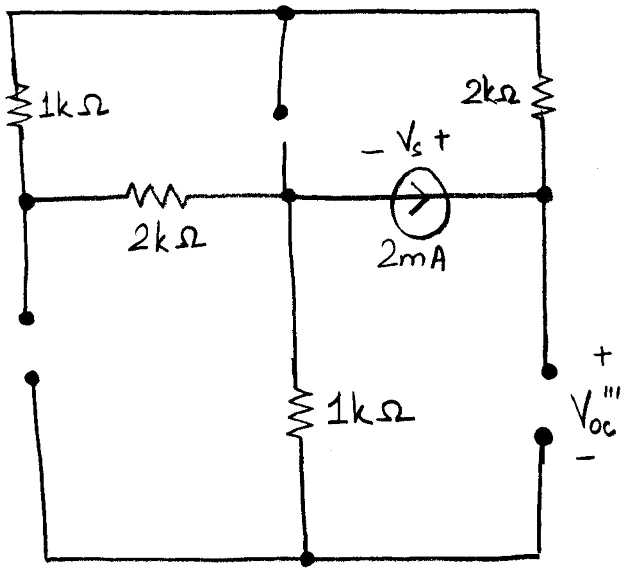


$$V_S = 1k(2m) + 2k(2m) = 2 + 4 = 6V$$

$$V'_{oc} = 6V$$



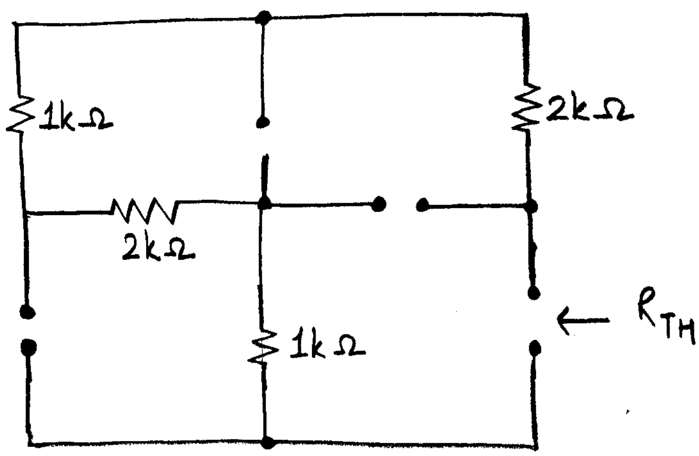
$$V''_{oc} = 2k(4m) + 1k(4m) = 8 + 4 = 12V$$



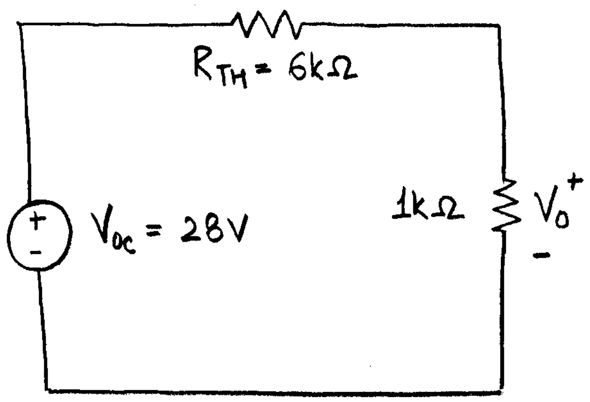
$$V_s = 2k(2m) + 1k(2m) + 2k(2m) = 10V$$

$$V_{oc}''' = 10V$$

$$V_{oc} = 6 + 12 + 10 = 28V$$



$$R_{TH} = 6k\Omega$$



$$V_o = \left(\frac{1k}{1k + 6k}\right)(28) = 4V$$

5.32 Find I_o in the circuit in Fig. P5.32 using Thévenin's theorem.

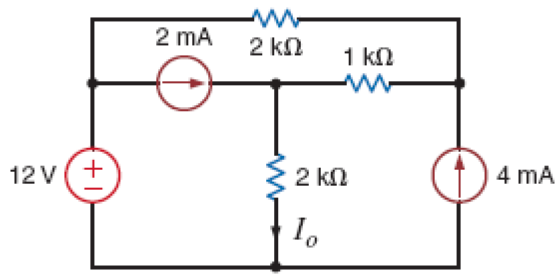
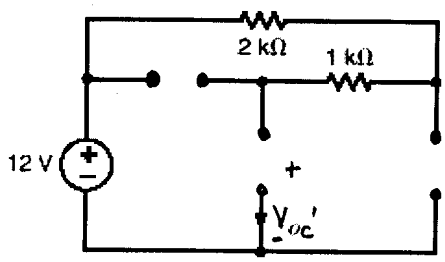
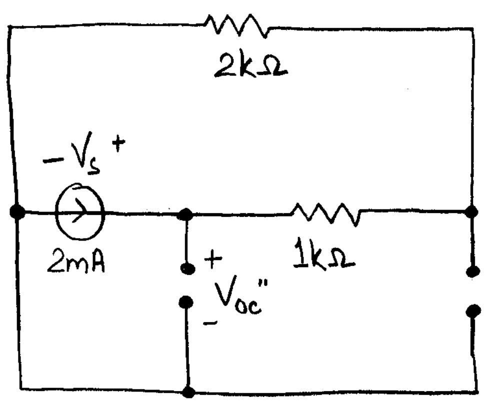


Figure P5.32

SOLUTION:

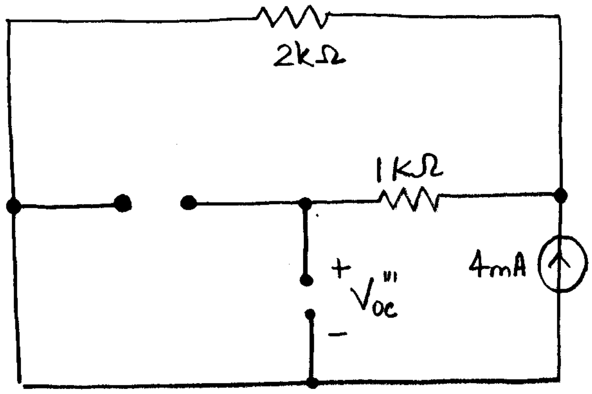


$$V'_{oc} = 12V$$



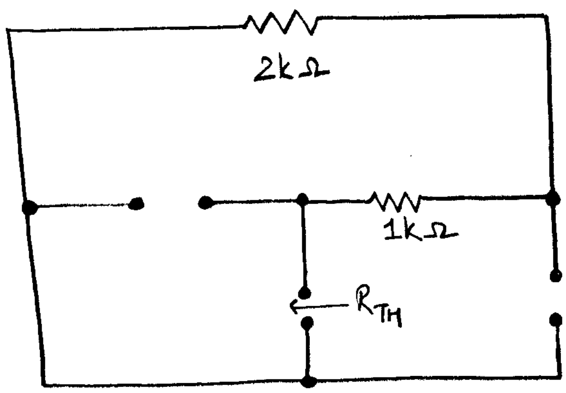
$$V_s = 1k(2m) + 2k(2m) = 2+4 = 6V$$

$$V''_{oc} = 6V$$

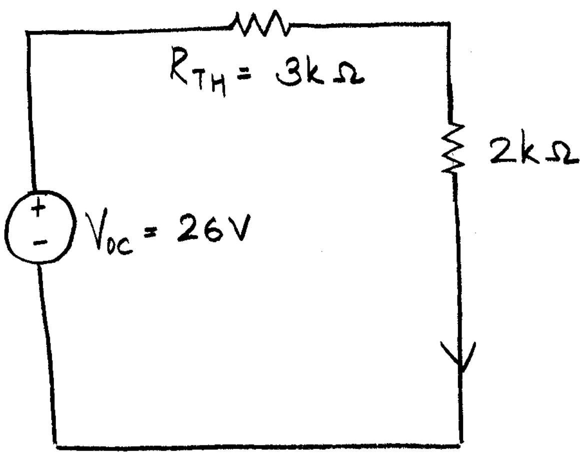


$$V_{oc}''' = 2k(4m) = 8V$$

$$V_{oc} = 12+6+8 = 26V$$



$$R_{TH} = 3k\Omega$$



$$I_o = \frac{26}{5k} = 5.2mA$$

5.33 Find V_o in the network in Fig. P5.33 using Thévenin's theorem.

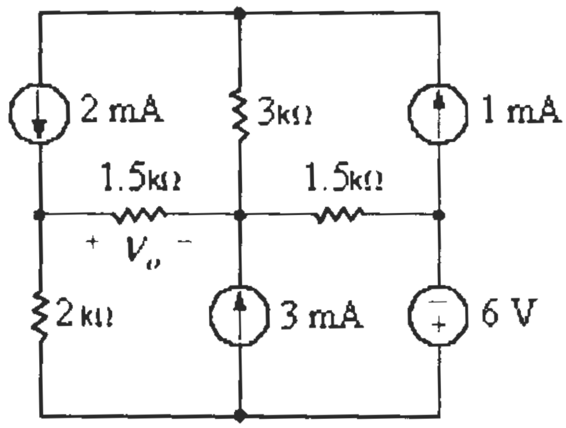
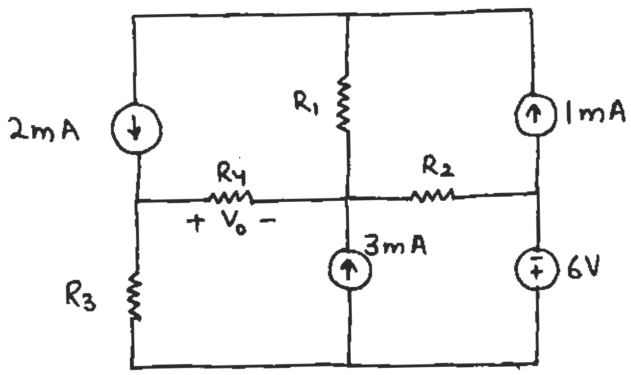
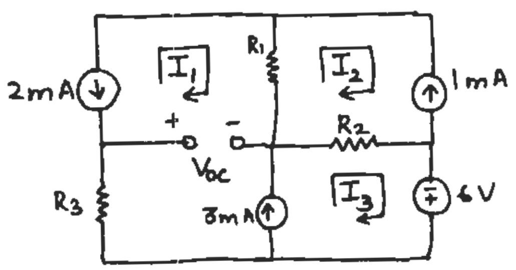


Figure P5.33

Solution: 5.33



$R_1 = 3k\Omega$, $R_2 = R_4 = 1.5\ k\Omega$, $R_3 = 2\ k\Omega$

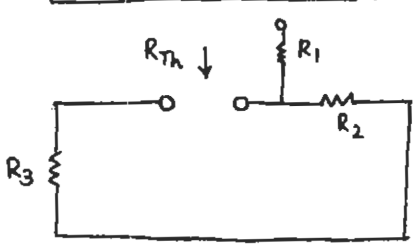


$I_1 = -2\ mA$, $I_2 = -1\ mA$

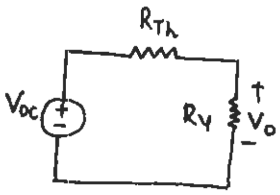
$I_3 - I_1 = 3mA \Rightarrow I_3 = 1mA$

$I_1 R_3 + V_{oc} + (I_3 - I_2) R_2 - 6 = 0$

$V_{oc} = 7V$



$R_{Th} = R_3 + R_2 = 3.5\ k\Omega$



$$V_o = V_{oc} \cdot \frac{R_4}{R_4 + R_{Th}}$$

$$\boxed{V_o = 2.10\,V}$$

5.34 Using Thévenin's theorem, find I_A in the circuit in Fig. P5.34.

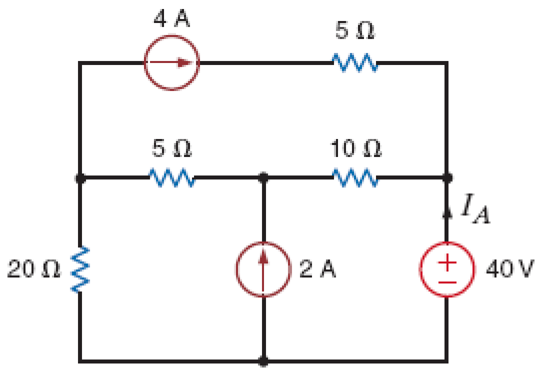
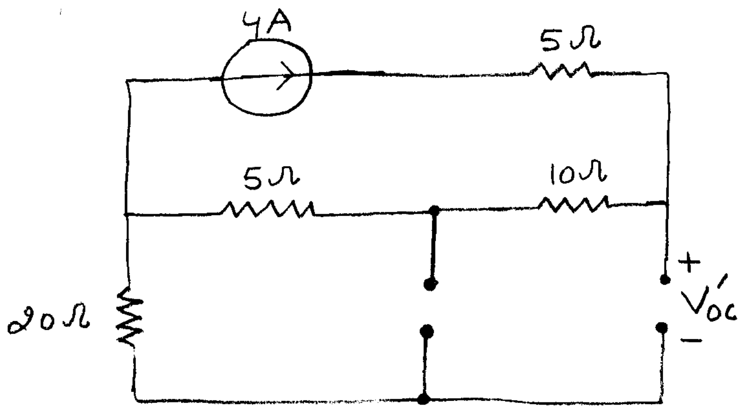
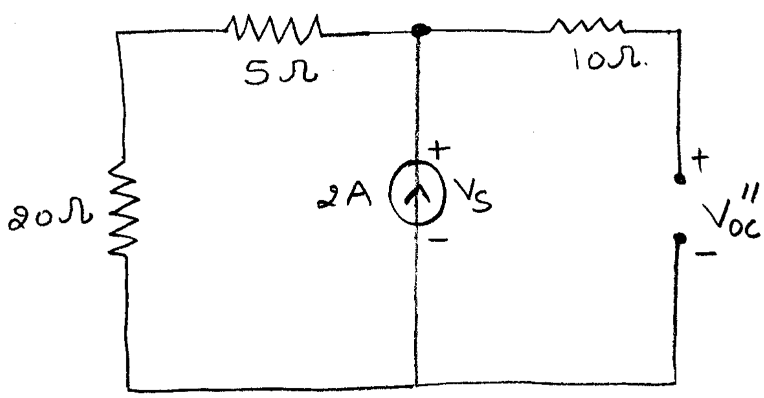


Figure P5.34

SOLUTION:



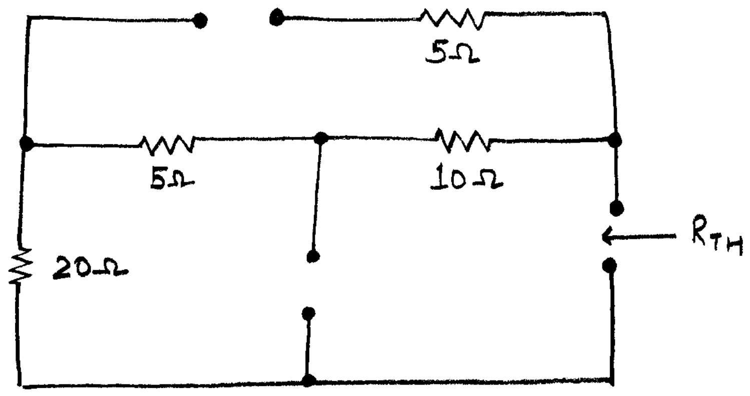
$$V_{oc}' = 5(4) + 10(4) = 60\text{V}$$



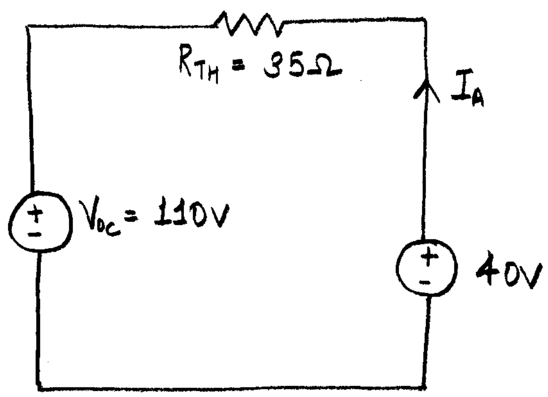
$$V_S = 5(2) + 20(2) = 50\text{V}$$

$$V_{oc}'' = 50\text{V}$$

$V_{oc} = 60 + 50 = 110V$



$R_{TH} = 35\Omega$



KVL: $40 = 110 + I_A(35)$

$I_A = -2A$

5.35 Find V_o in the network in Fig. P5.35 using Thévenin's theorem.

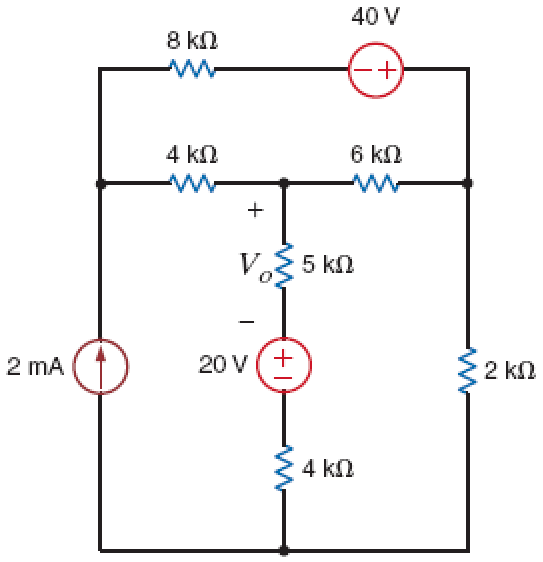
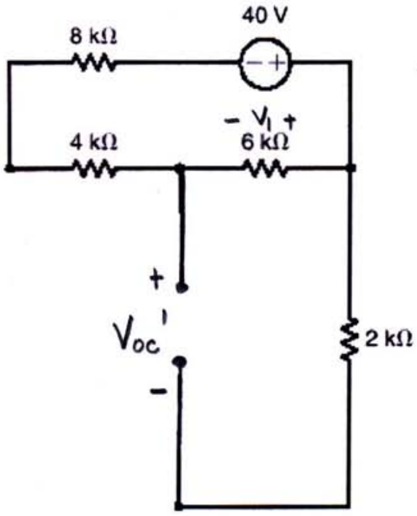


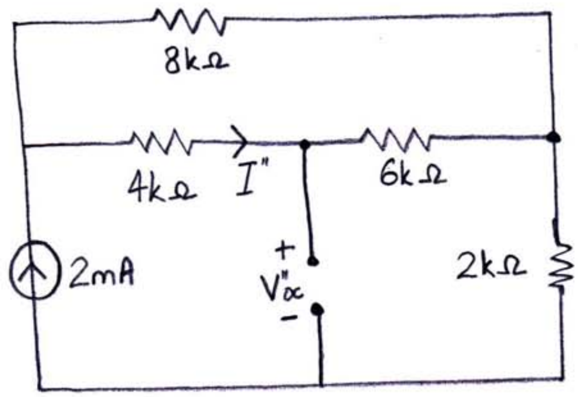
Figure P5.35

SOLUTION:



$$V_1 = \left(\frac{6k}{6k + 4k + 8k}\right)(40) = \frac{40}{3}\text{ V}$$

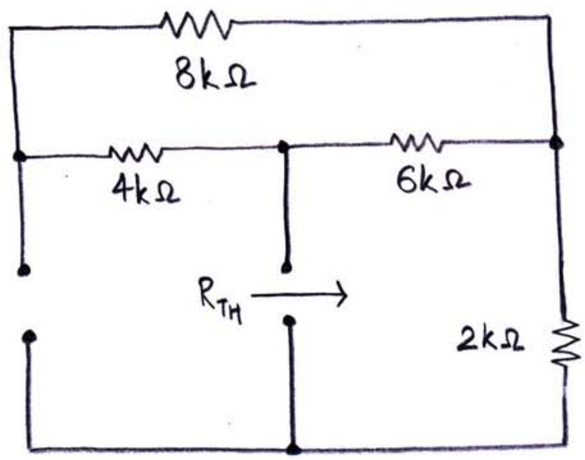
$$V_{oc}' = -\frac{40}{3}\text{ V}$$



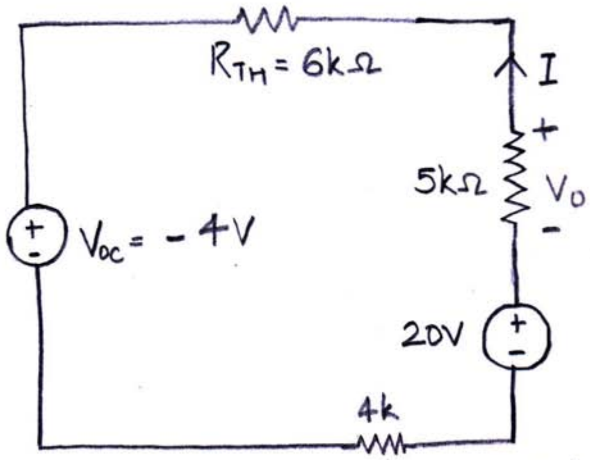
$$I'' = \left(\frac{8k}{8k+4k+6k}\right)(2m) = 0.89mA$$

$$V''_{oc} = 6k(0.89m) + 2k(2m) = \frac{28}{3}V$$

$$V_{oc} = -\frac{40}{3} + \frac{28}{3} = -4V$$



$$R_{TH} = \left[(4k+8k) \,||\, 6k\right] + 2k = 6k\Omega$$



$$20 = -4 + (6k + 5k + 4k)I$$
$$I = 1.6mA$$
$$V_o = -5k(1.6m) = -8V$$

5.36 Use Thévenin's theorem to find I_o in the network in Fig. P5.36.

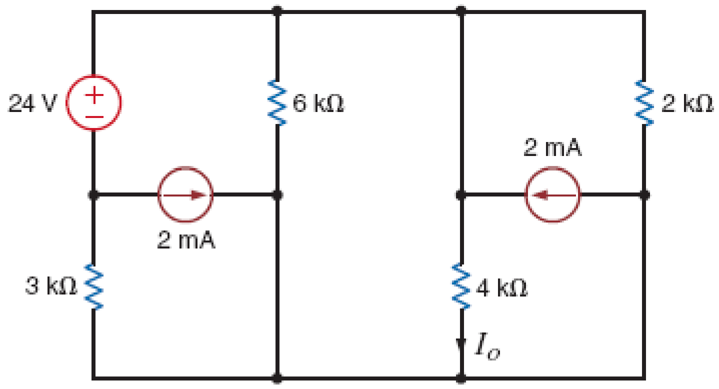
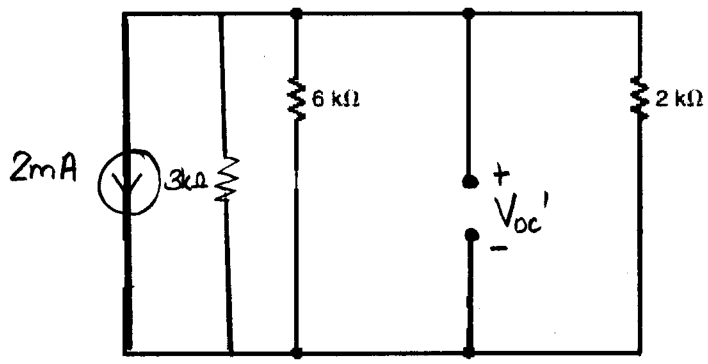
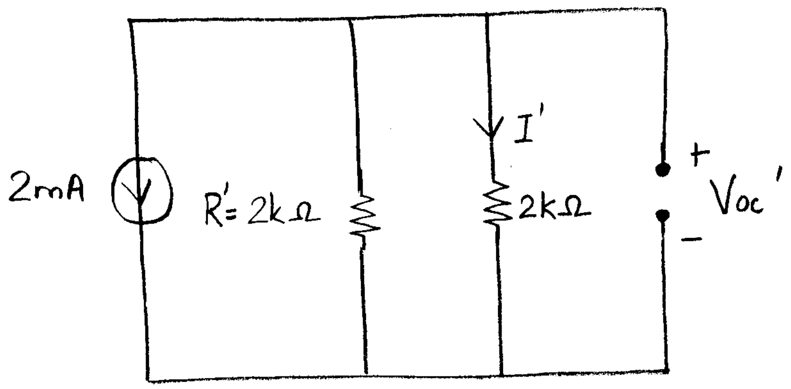


Figure P5.36

SOLUTION:

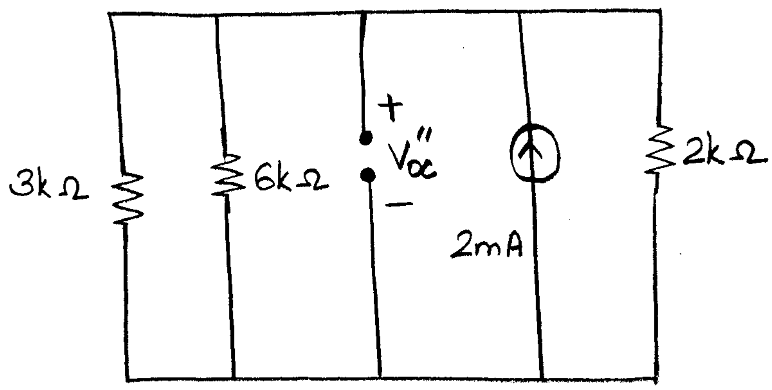


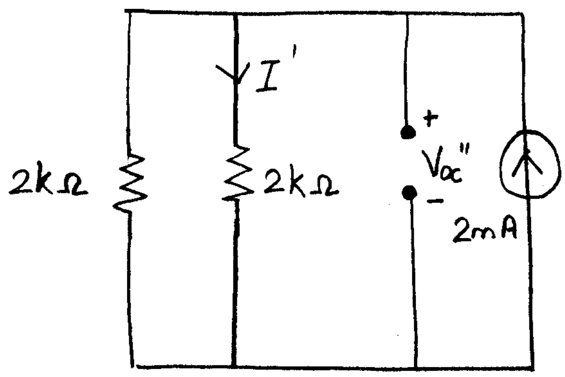
$$R' = 3k \| 6k = 2k\Omega$$



$$I' = \left(\frac{2k}{2k+2k}\right)(-2m) = -1mA$$

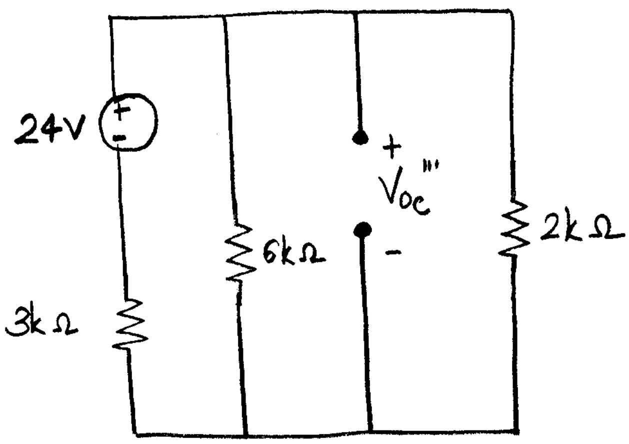
$$V'_{oc} = 2k(-1m) = -2V$$

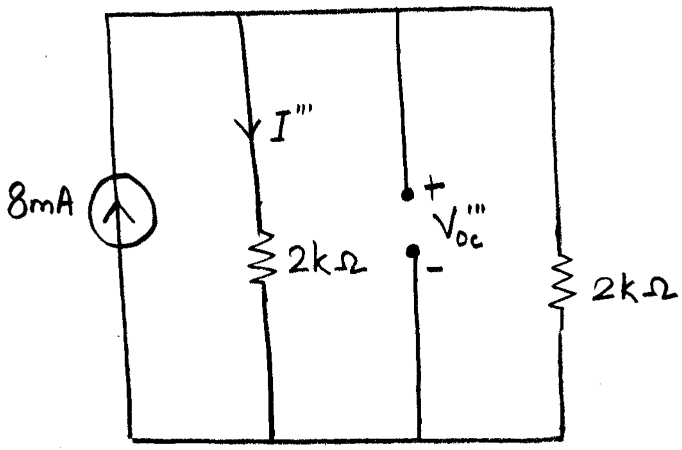




$$I' = \left(\frac{2k}{2k + 2k}\right)(2m) = 1mA$$

$$V''_{oc} = 2k\,(1m) = 2V$$

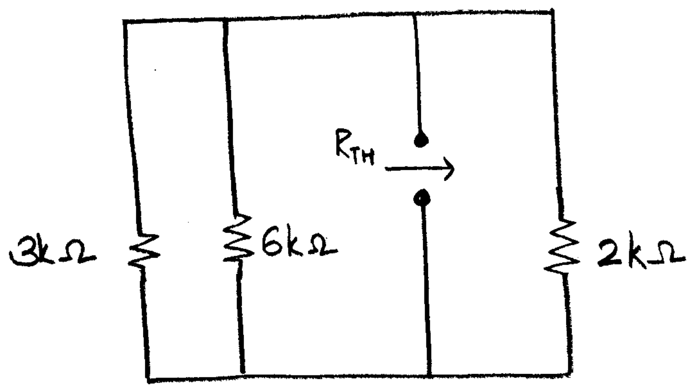




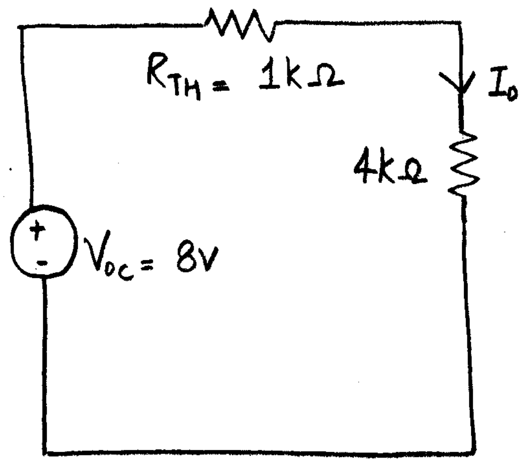
$$I''' = \left(\frac{2k}{2k + 2k}\right)(8m) = 4mA$$

$$V'''_{oc} = 2k(4m) = 8V$$

$$V_{oc} = -2 + 2 + 8 = 8V$$



$$R_{TH} = (3k \| 6k) \| 2k = 1k\Omega$$



$$I_o = \frac{8}{1k + 4k} = 1.6mA$$

5.37 Find I_o in the network in the Fig. P5.37 using Thévenin's theorem.

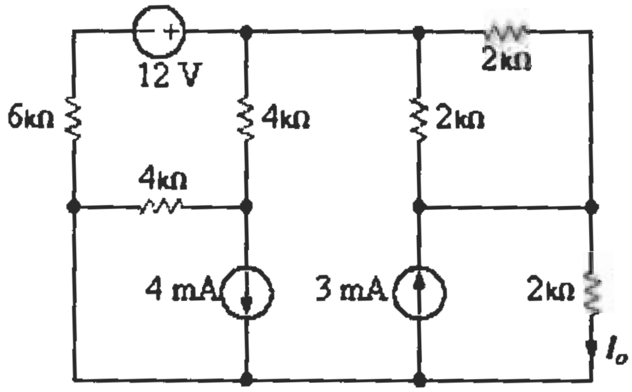
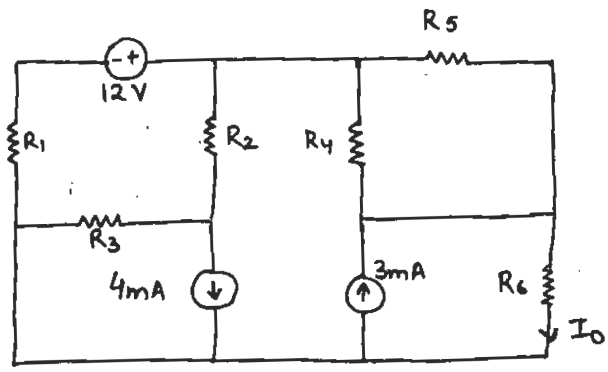
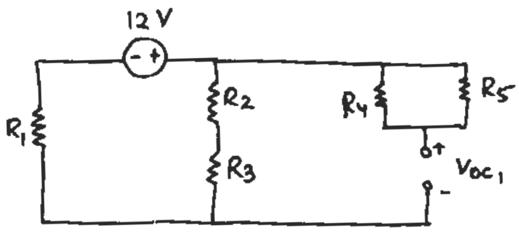


Figure P5.37

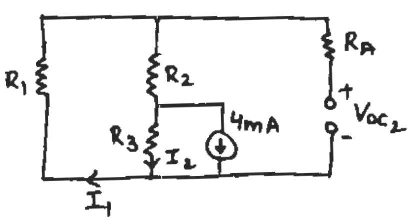
Solution: 5.37



$R_1 = 6\,k\Omega, \quad R_2 = R_3 = 4\,k\Omega, \quad R_4 = R_5 = R_6 = 2\,k\Omega$



$$V_{oc_1} = 12\,\frac{R_2 + R_3}{R_1 + R_2 + R_3} = 6.86\ V$$

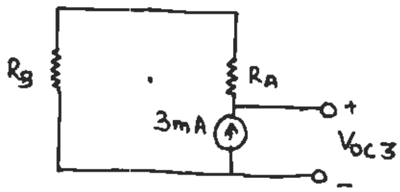


$$R_A = R_4 \parallel R_5 = 1\,k\Omega$$

$$I_1 = 4\times10^{-3}\cdot\frac{R_3}{R_1 + R_2 + R_3} = 1.14\ mA$$

$$I_2 = -4\times10^{-3}\cdot\frac{R_1 + R_2}{R_1 + R_2 + R_3} = -2.86\ mA$$

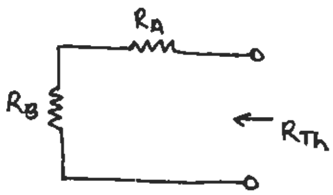
$$V_{oc_2} = I_1 R_2 + I_2 R_3 = -6.87\ V$$



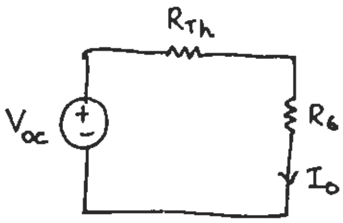
$$R_B = R_1 \| (R_2 + R_3) = 3.43\ k\Omega$$

$$V_{oc_3} = 3 \times 10^{-3} (R_A + R_B) = 13.3V$$

$$V_{oc} = V_{oc_1} + V_{oc_2} + V_{oc_3} = 13.3\ V$$



$$R_{Th} = R_A + R_B = 4.43\,k\Omega$$



$$I_o = \frac{V_{oc}}{R_6 + R_{Th}}$$

$$= \frac{13.284}{2 + 4.428}$$

$$= 2.0665 = 2.07\,mA$$

$$\boxed{I_o = 2.07\,mA}$$

5.38 Given the linear circuit in Fig. P5.38, it is known that when a 2-kΩ load is connected to the terminals *A-B*, the load current is 16 mA. If a 14-kΩ load is connected to the terminals, the load current is 14 mA. Find the current in a 28-kΩ load.

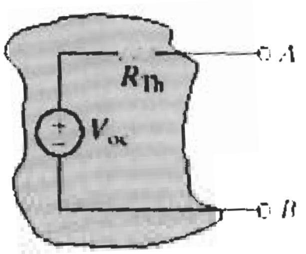
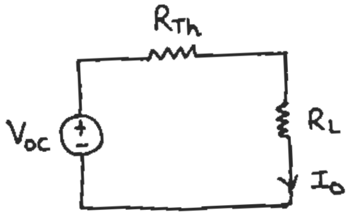


Figure P5.38

Solution: 5.38



$$I_o = \frac{V_{oc}}{R_{Th} + R_L} \quad \text{—} \quad (1)$$

Case 1 $\quad R_L = 2\ k\Omega, \quad I_o = 16\,mA$

From equation (1) : $\quad 16 \times 10^{-3} = \dfrac{V_{oc}}{R_{Th} + 2\times10^3}$

$$V_{oc} = 16\times10^{-3}(R_{Th} + 2\times10^3) \quad \text{—} \quad (2)$$

Case 2 $\quad R_L = 14\,k\Omega, \quad I_o = 14\,mA$

From equation (1) : $\quad 14\times10^{-3} = \dfrac{V_{oc}}{R_{Th} + 14\times10^3}$

$$V_{oc} = 14\times10^{-3}(R_{Th} + 14\times10^3) \quad \text{—} \quad (3)$$

From equations (2) and (3), we get

$R_{Th} = 82\,k\Omega, \quad V_{oc} = 1344\ V$

Case 3 $\quad R_L = 28\ k\Omega$

$$I_o = \frac{V_{oc}}{R_{Th} + R_L}$$

$$\boxed{I_o = 12.2\,mA}$$

5.39 If an 8-kΩ load is connected to the terminals of the network in Fig. P5.39, $V_{AB} = 16\ \Omega$. If a 2-kΩ load is connected to the terminals, $V_{AB} = 8$ V. Find V_{AB} if a 20-kΩ load is connected to the terminals.

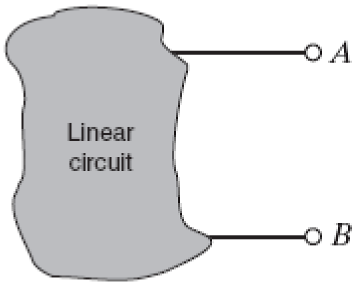
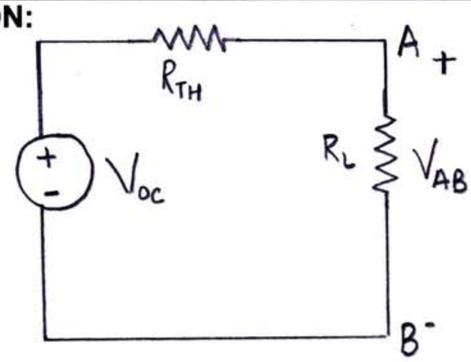


Figure P5.39

SOLUTION:



$$V_{AB} = \left(\frac{R_L}{R_L + R_{TH}}\right)(V_{oc})$$

$$16 = \left(\frac{8k}{8k + R_{TH}}\right)(V_{oc})$$

$$V_{oc} = \frac{16(8k + R_{TH})}{8k}$$

$$8 = \left(\frac{2k}{2k + R_{TH}}\right)(V_{oc})$$

$$\frac{16(8k + R_{TH})}{8k} = \frac{8(2k + R_{TH})}{2k}$$

$$R_{TH} = 4k\Omega$$

$$V_{oc} = \frac{16(8k + 4k)}{8k} = 24V$$

$$V_{AB} = \left(\frac{20k}{20k + 4k}\right)(24) = 20V$$

5.40 Find I_o in the network in Fig. P5.40 using Norton's theorem.

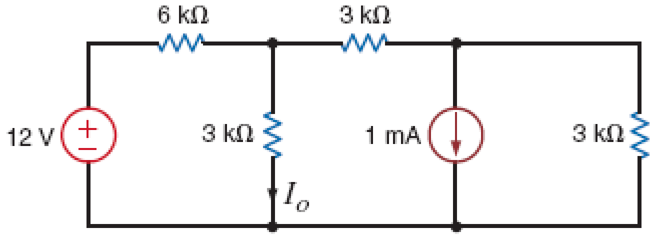
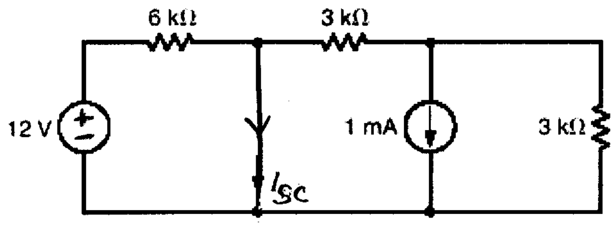
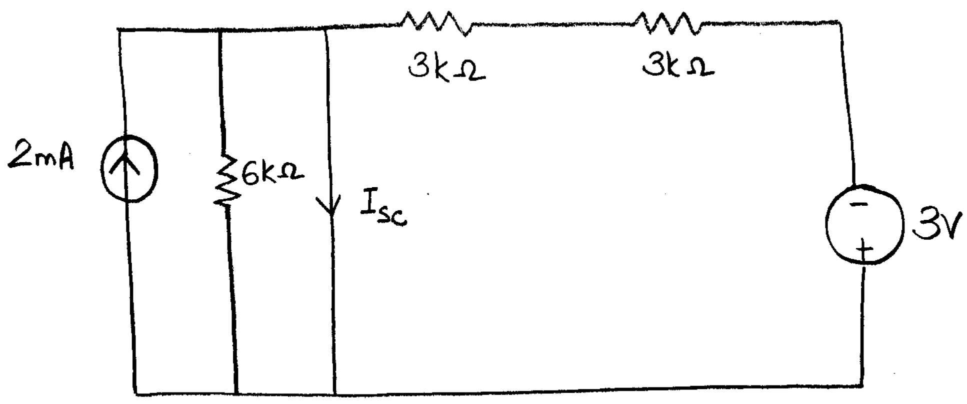


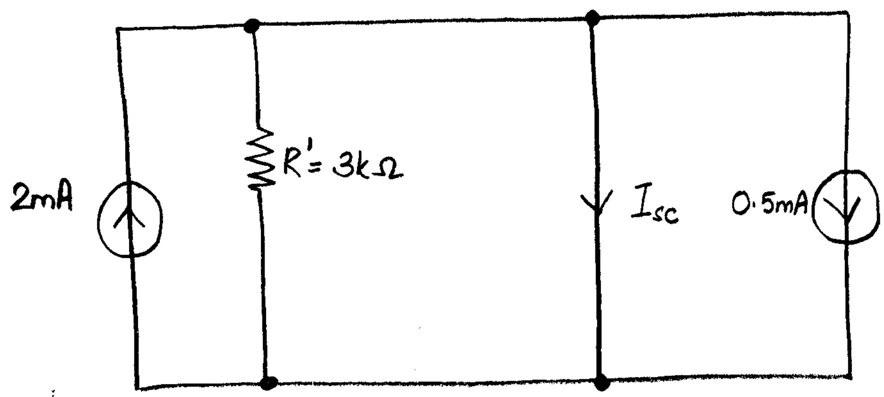
Figure P5.40

SOLUTION:

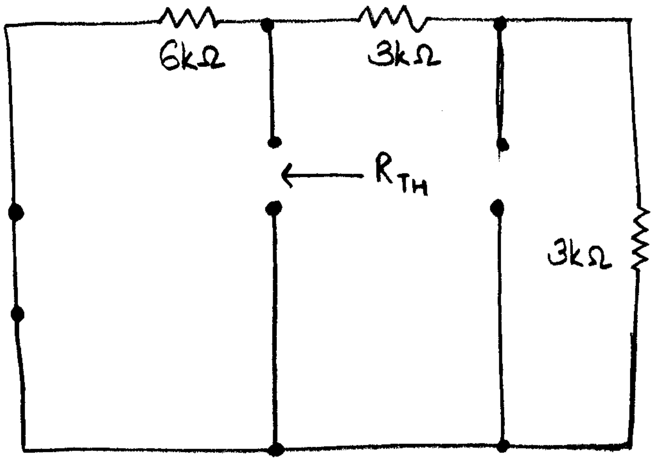




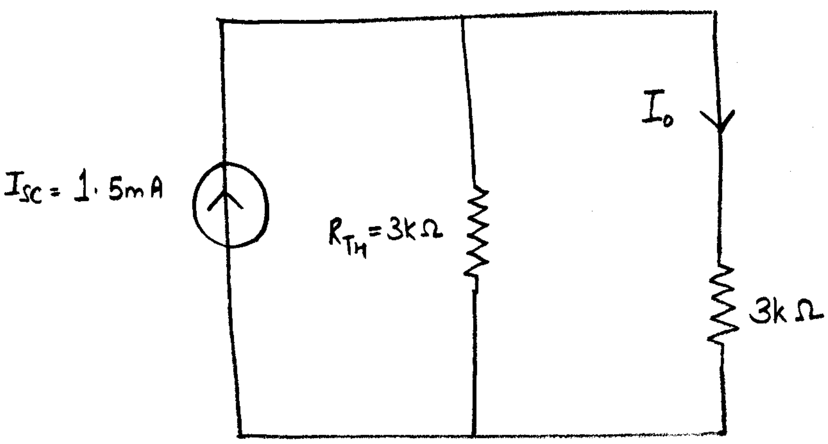
$R' = 6k || 6k = 3k\Omega$



$I_{sc} = 2m - 0.5m = 1.5mA$



$$R_{TH} = (6k \| 6k) = 3k\,\Omega$$



$$I_o = \left(\frac{3k}{3k + 3k}\right)(1.5m) = 0.75mA$$

5.41 Use Norton's theorem to find I_o in the circuit in Fig. P5.41.

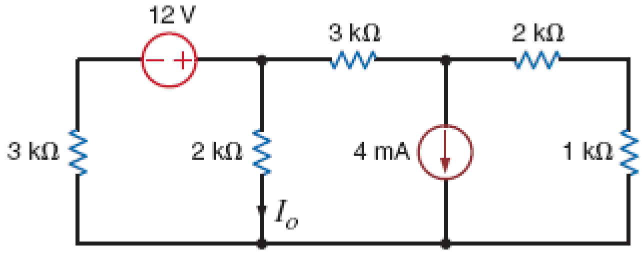
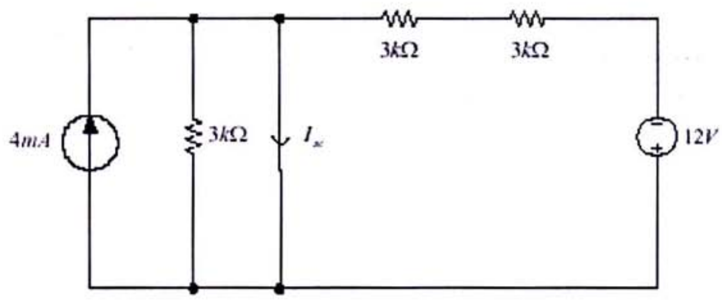
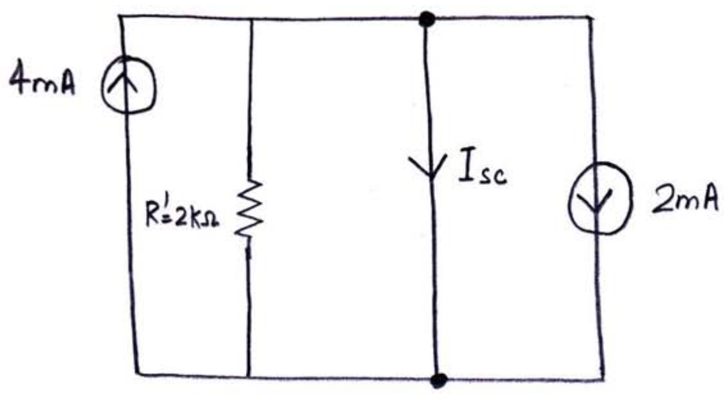


Figure P5.41

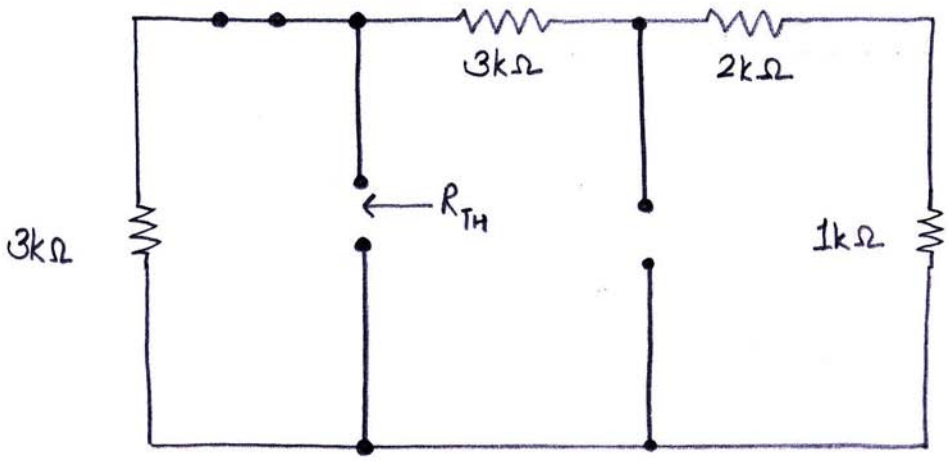
SOLUTION:



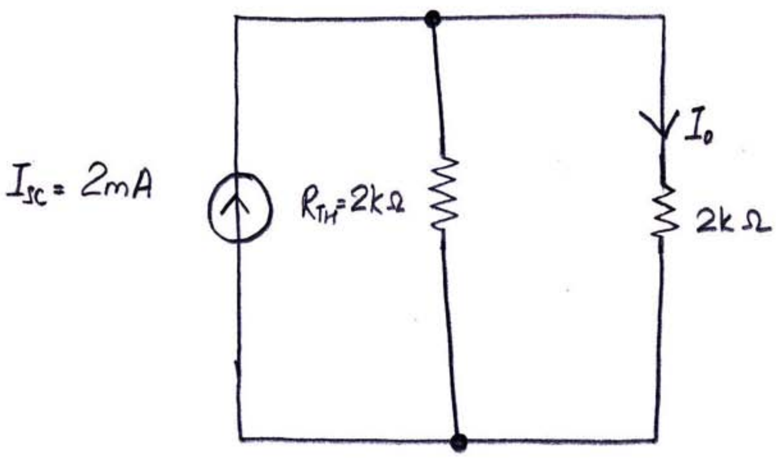
$$R' = 6k \| 3k = 2k\,\Omega$$



$$I_{sc} = 4m - 2m = 2mA$$



$$R_{TH} = (3k \| 6k) = 2k\Omega$$



$$I_0 = \left(\frac{2k}{2k + 2k}\right)(2m) = 1mA$$

5.42 Use Norton's theorem to find I_o in the circuit in Fig. P5.42.

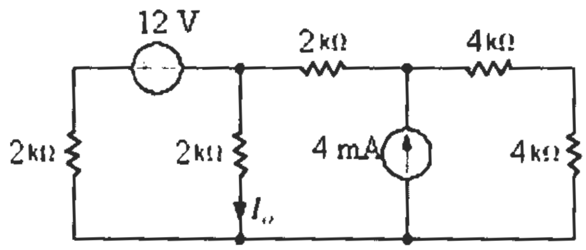
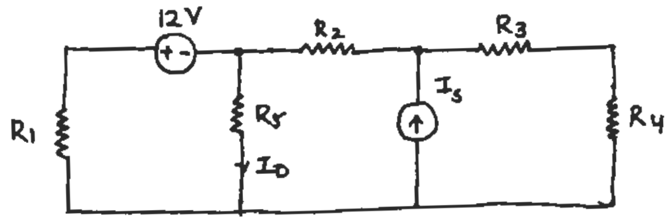


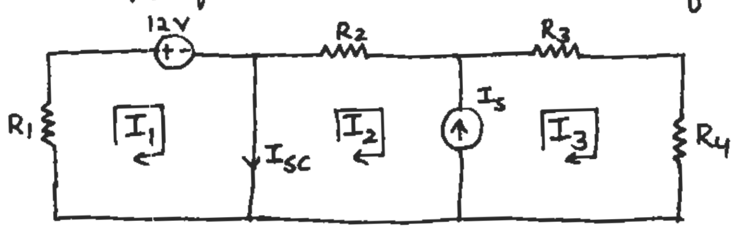
Figure P5.42

Solution: 5.42



$R_1 = R_2 = R_5 = 2k\Omega$; $R_3 = R_4 = 4\ k\Omega$, $I_S = 4\ mA$

[To apply Norton's theorem we first short circuit current]



$I_1 = \frac{-12}{R_1} = -6mA$

$R_2 I_2 + (R_3 + R_4) I_3 = 0$ — (1)

$I_3 - I_2 = I_s = 4mA$ — (2)

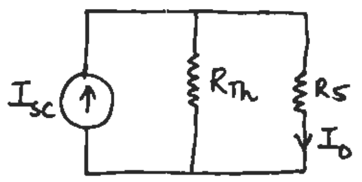
From equations (1) and (2)

$I_3 = 0.8\ mA$

$I_2 = -3.2\ mA$

$I_{SC} = I_1 - I_2 = -2.8\ mA$

$R_{Th} = R_1 \parallel (R_2 + R_3 + R_4) = \frac{5}{3} k\Omega$



$$I_o = I_{sc} \frac{R_{Th}}{R_{Th} + R_5}$$

$$\boxed{I_o = -1.27 \text{ mA}}$$

5.43 Find I_o in the network in Fig. P5.43 using Norton's theorem.

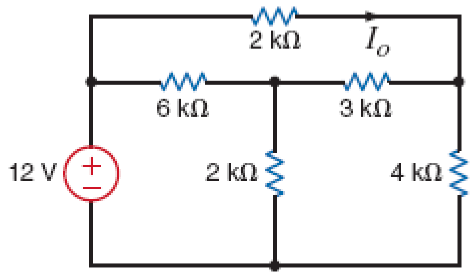
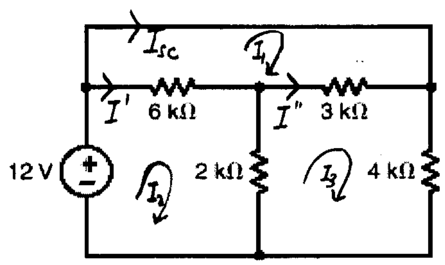


Figure P5.43

SOLUTION:



$$I_1 = I_{sc}$$
$$I_2 = I' + I_{sc}$$
$$I' = I_2 - I_1$$
$$I'' + I_1 = I_3$$
$$I'' = I_3 - I_1$$
$$I = I_2 - I_3$$

KVL left loop : $12 = 6kI' + 2kI$

$$12 = 6k(I_2 - I_1) + 2k(I_2 - I_3)$$

KVL right loop: $3kI'' + 4kI_3 - I(2k) = 0$

$$3k(I_3 - I_1) + 4kI_3 - (I_2 - I_3)(2k) = 0$$
$$-3kI_1 - 2kI_2 + 9kI_3 = 0$$

KVL outer loop: $12 = 4k\,I_3$

$I_3 = 3mA$

$-3k\,I_1 - 2k\,I_2 = -27$

$12 = -6k\,I_1 + 8k\,I_2 - 2k(3m)$

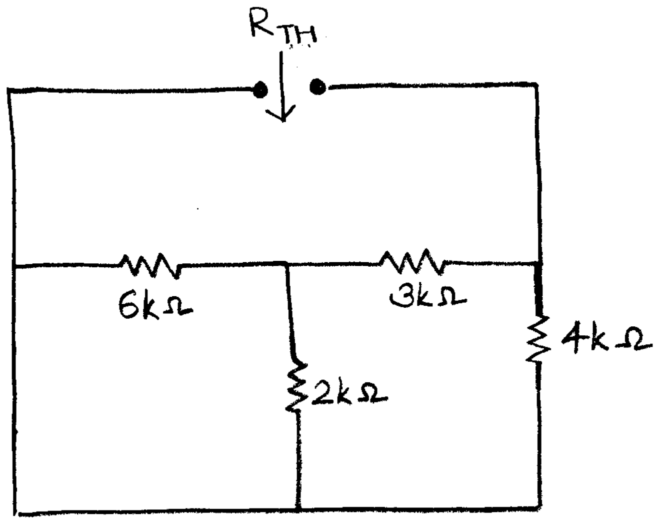
$-6k\,I_1 + 8k\,I_2 = 18$

$-3k\,I_1 - 2k\,I_2 = -27$

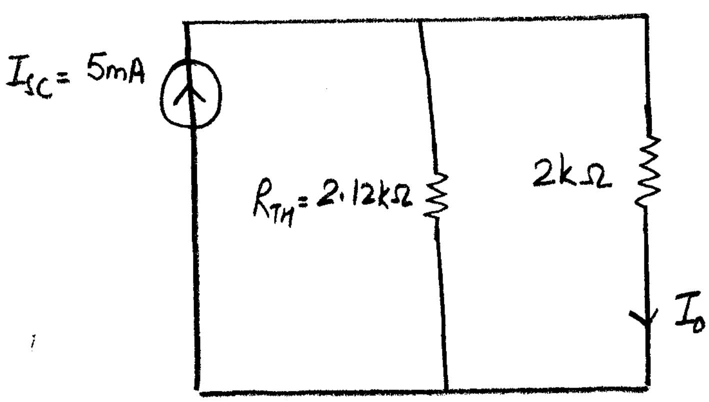
$I_1 = 5mA$

$I_2 = 6mA$

$I_{sc} = 5mA$



$$R_{TH} = \left[(6k \| 2k) + 3k\right] \| 4k = 2.12k\Omega$$



$$I_0 = \left(\frac{2.12k}{2.12k + 2k}\right)(5m) = 2.57mA$$

5.44 Use Norton's theorem to find V_o in the network in Fig. P5.44.

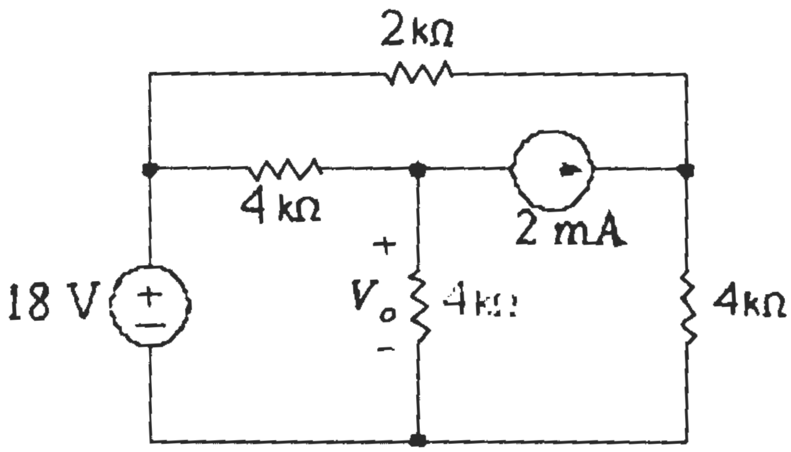
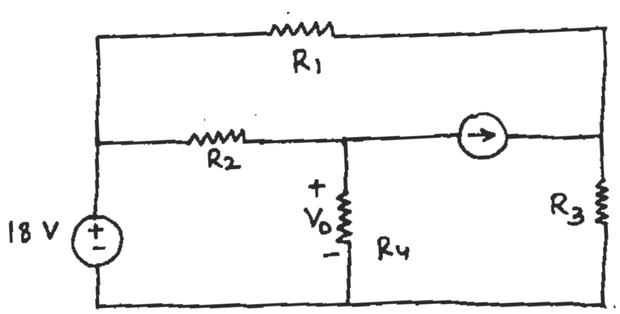
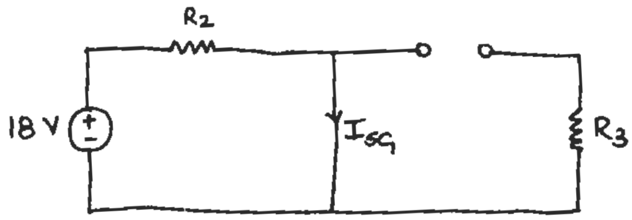


Figure P5.44

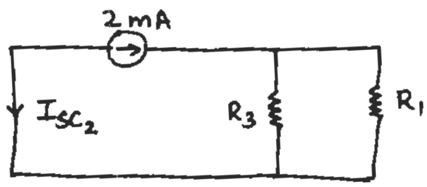
Solution: 5.44



$R_1 = 2k\Omega$,
$R_2 = R_3 = R_4 = 4k\Omega$

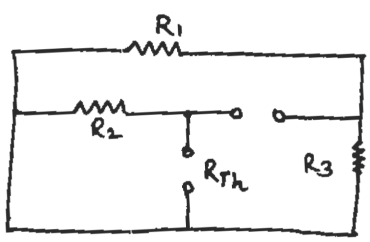


$$I_{sc_1} = \frac{18}{R_2} = 4.5 \text{ mA}$$

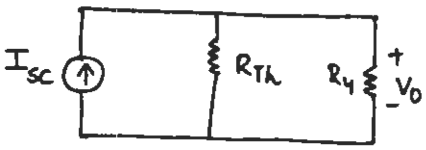


$$I_{sc_2} = -2 \text{ mA}$$

$$I_{sc} = I_{sc_1} + I_{sc_2} = 2.50 \text{ mA}$$



$$R_{Th} = R_2 = 4k\Omega$$



$$V_o = I_{SC}\left[R_{Th} \,||\, R_4\right]$$

$$\boxed{V_o = 5.00\text{ V}}$$

5.45 Use Norton's theorem to find V_o in the network in Fig. P5.45.

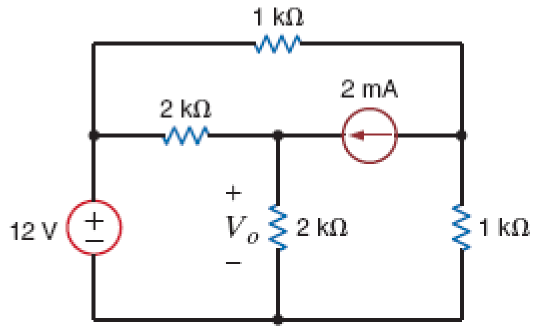
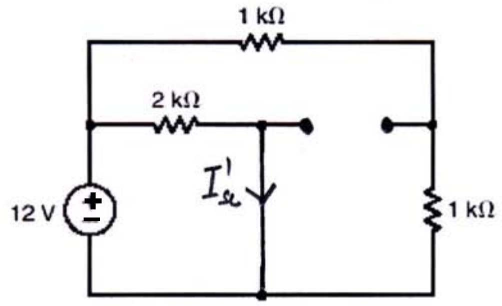
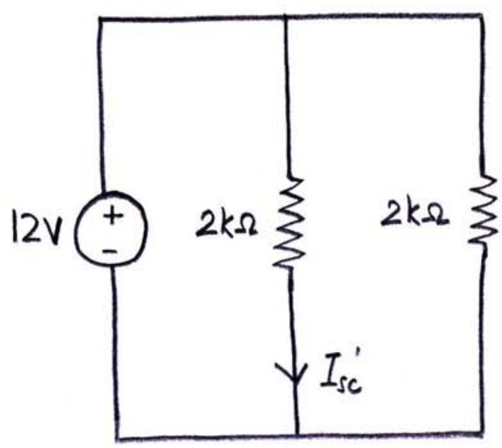


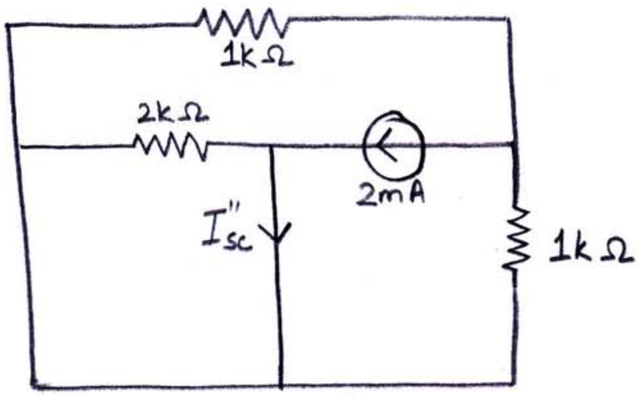
Figure P5.45

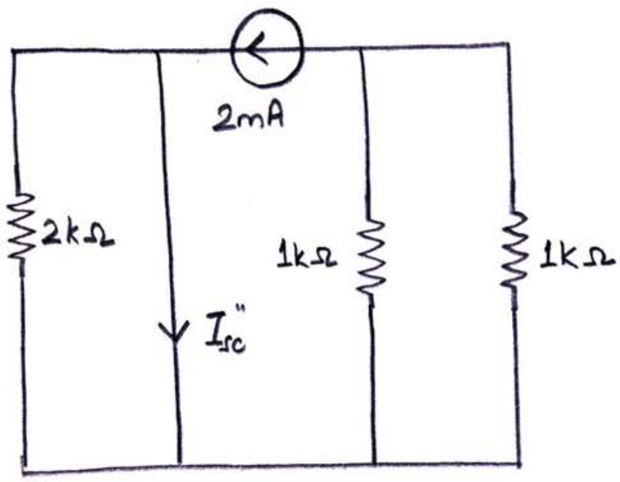
SOLUTION:





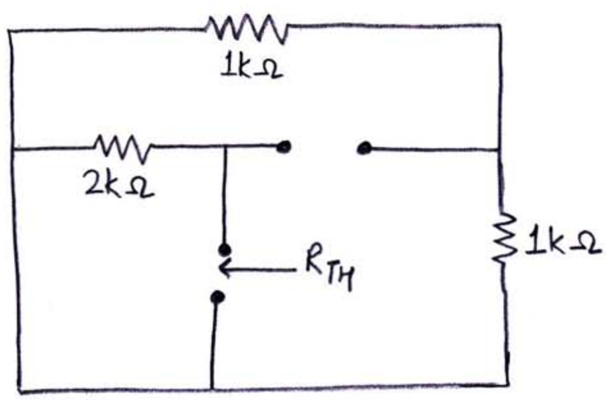
$$I'_{sc} = \frac{12}{2k} = 6mA$$



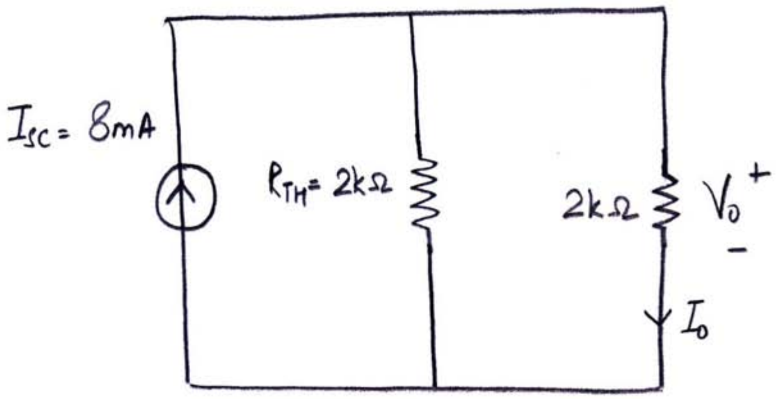


$$I''_{sc} = 2mA$$

$$I_{sc} = 6m + 2m = 8mA$$



$$R_{TH} = 2k\Omega$$



$$I_o = \left(\frac{2k}{2k+2k}\right)(8m) = 4mA$$

$$V_o = 2k(4m) = 8V$$

5.46 Find V_o in the network in Fig. P5.46 using Norton's theorem.

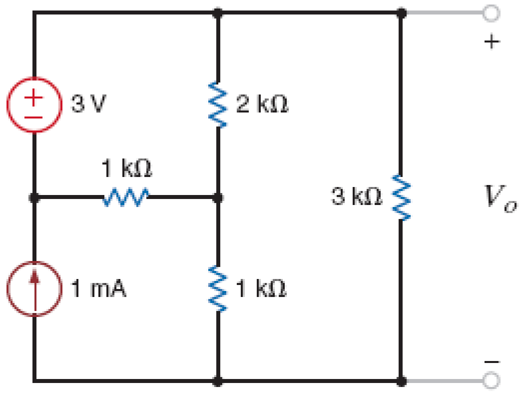
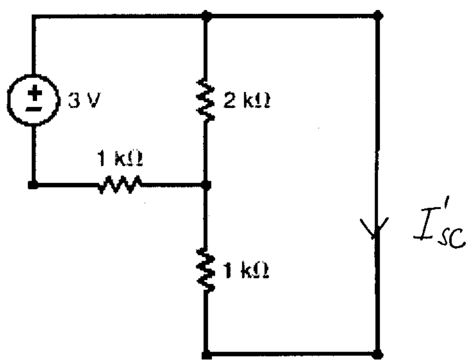
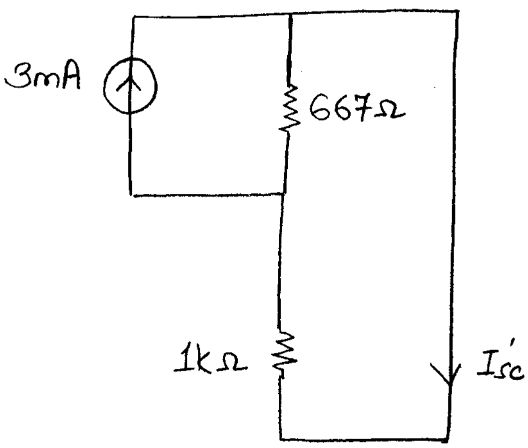


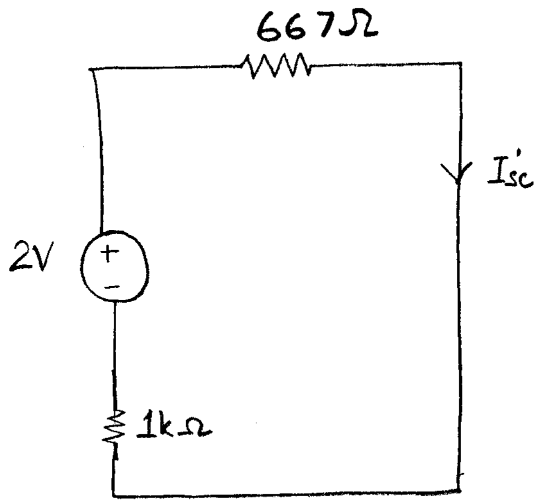
Figure P5.46

SOLUTION:

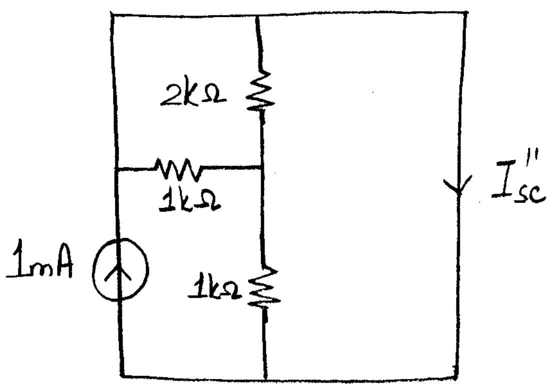


$$R' = 1k \| 2k = 667\Omega$$



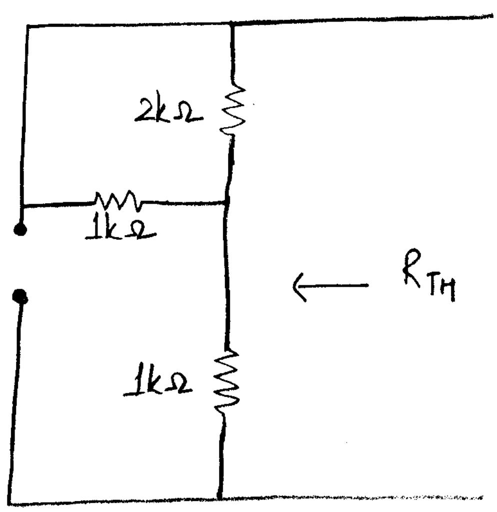


$$I'_{sc} = \frac{2}{1k + 667} = 1.2mA$$

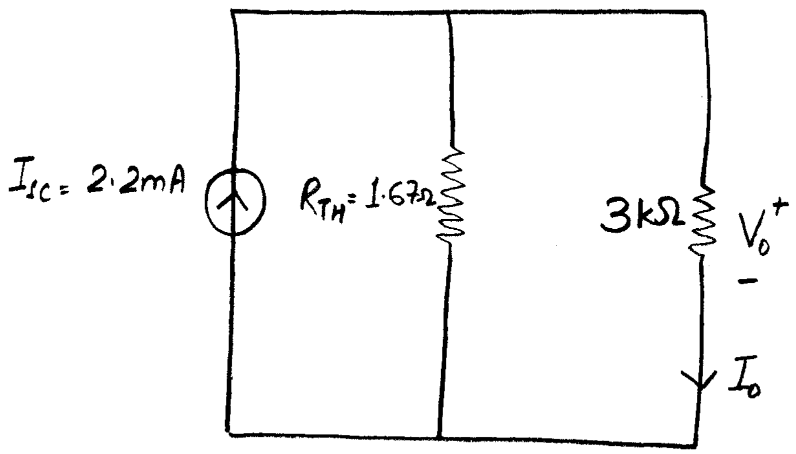


$$I''_{sc} = 1mA$$

$$I_{sc} = 1.2m + 1m = 2.2mA$$



$$R_{TH} = (1k \| 2k) + 1k = 1.67\,\Omega$$



$$I_o = \left(\frac{1.67k}{1.67k + 3k}\right)(2.2m) = 0.787mA$$

$$V_o = (0.787m)(3k) = 2.36\,V$$

5.47 Find I_o in the network in Fig. P5.47 using Norton's theorem.

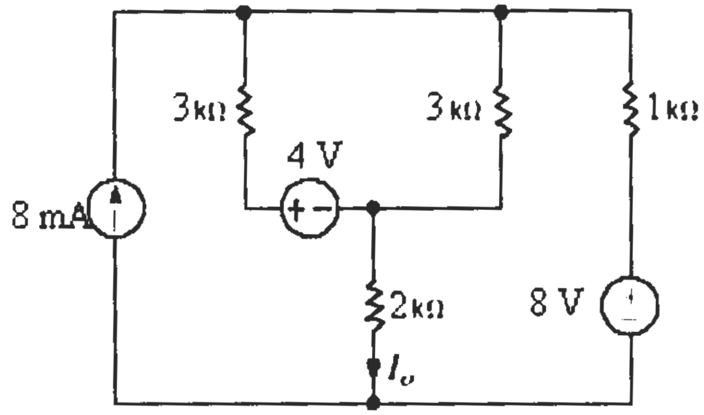
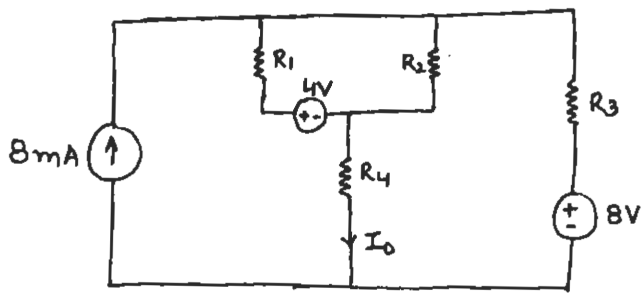
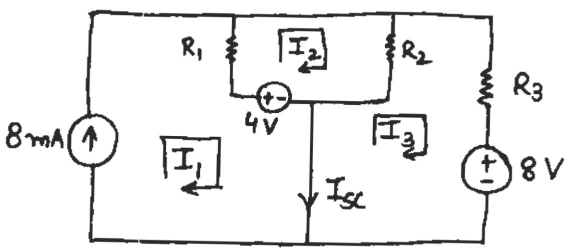


Figure P5.47

Solution: 5.47



$R_1 = R_2 = 3k\Omega$; $R_3 = 1k\Omega$; $R_4 = 2k\Omega$



$$I_1 = 8mA \quad \text{①}$$

KVL @ I_2 : $(I_2 - I_1)R_1 + (I_2 - I_3)R_2 - 4 = 0$

$$6I_2 - 3I_3 = 28 \times 10^{-3} \quad \text{②}$$

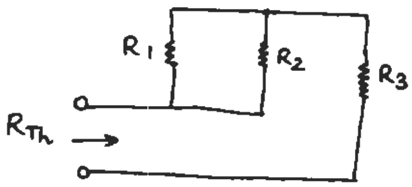
KVL @ I_3 : $(I_3 - I_2)R_2 + I_3 R_3 + 8 = 0$

$$4I_3 - 3I_2 = -8 \times 10^{-3} \quad \text{③}$$

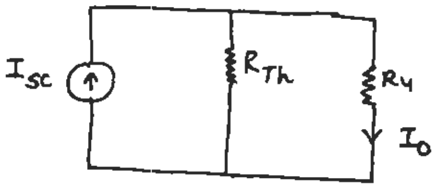
From equations 2 and 3, we get

$$I_3 = 2.4 \text{ mA}$$

$$I_{SC} = I_1 - I_3 = 5.6 \text{ mA}$$



$$R_{Th} = (R_1 \| R_2) + R_3 = 2.5 \text{ k}\Omega$$



$$I_o = I_{SC} \frac{R_{Th}}{R_{Th} + R_4}$$

$$\boxed{I_o = 3.11 \text{ mA}}$$

5.48 Find V_o in the circuit in Fig. P5.48 using Norton's theorem.

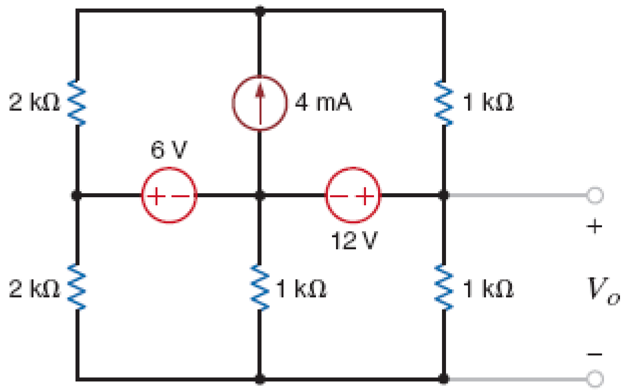
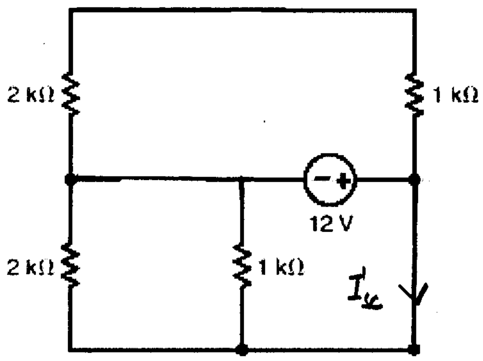
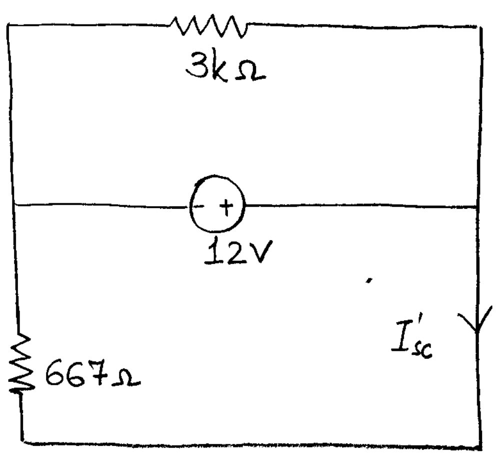


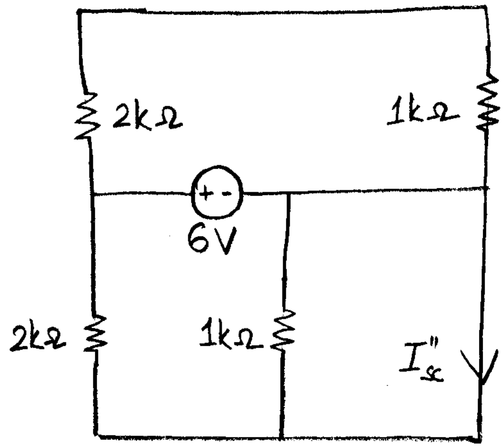
Figure P5.48

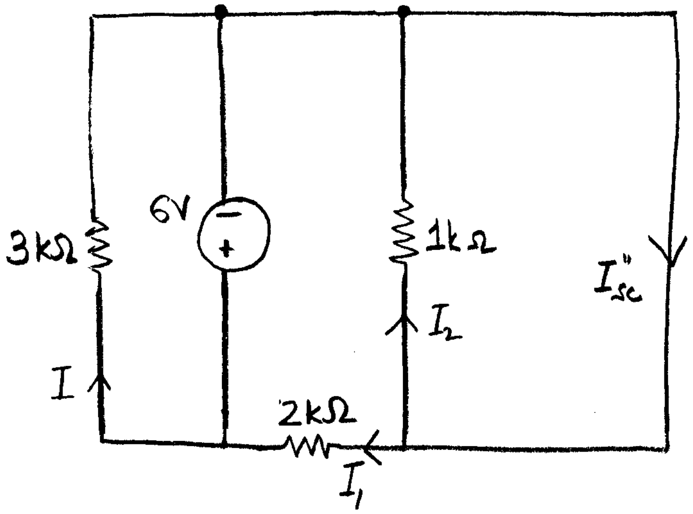
SOLUTION:





$$I'_{sc} = \frac{12}{667} = 18mA$$

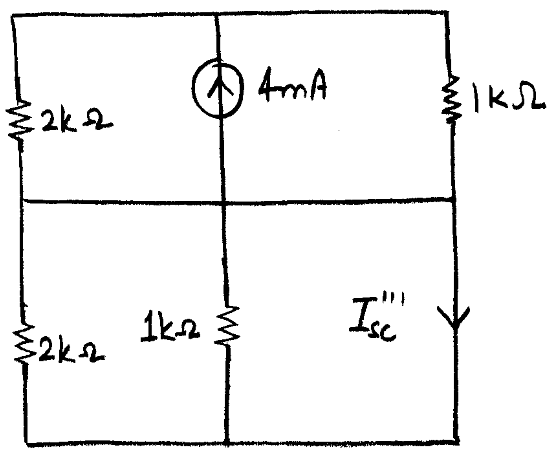


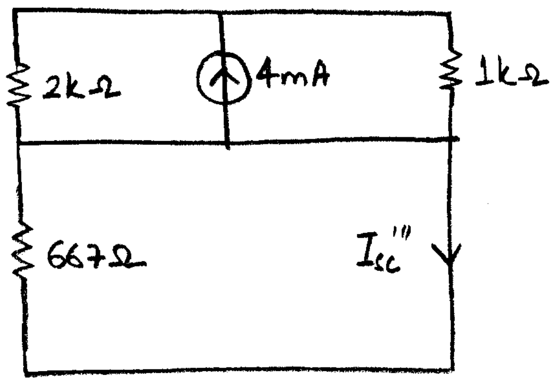


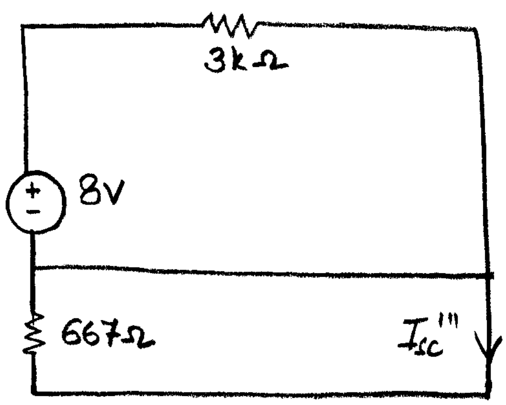
$$I = \frac{6}{3k} = 2mA$$

KVL around the outer loop : $3kI + 2kI_1 = 0$

$$I_{sc}'' = I_1 = -3mA$$



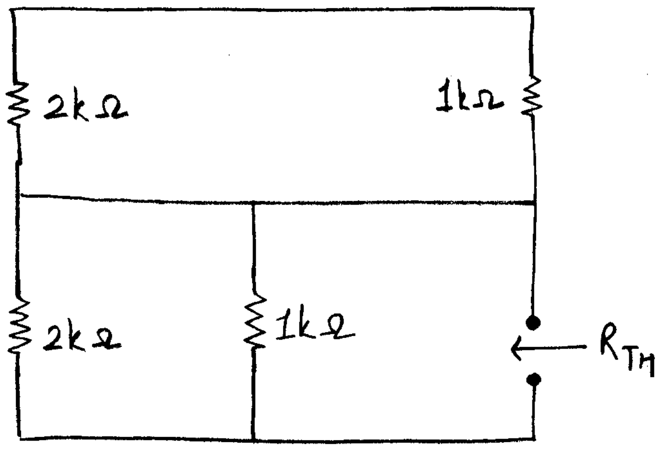




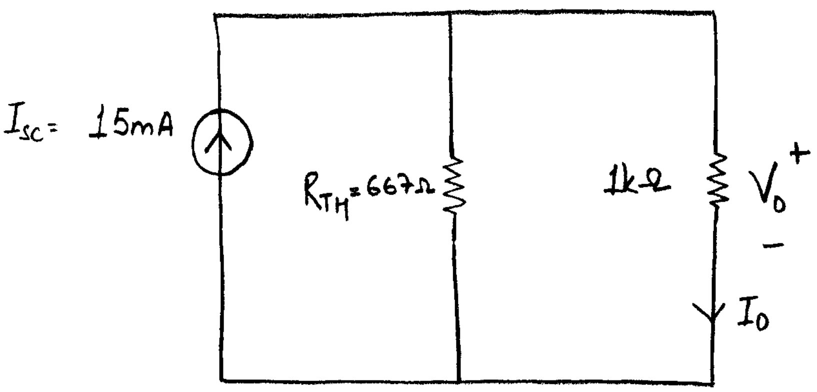
KVL around outer loop yields:

$$I_{sc}''' = 0\text{A}$$

$$I_{sc} = 18m - 3m + 0 = 15\text{mA}$$



$R_{TH} = 2k \| 1k = 667\Omega$



$$I_0 = \left(\frac{667}{667 + 1k}\right)(15m) = 6mA$$

$$V_0 = 6m(1k) = 6V$$

5.49 Use Norton's theorem to find I_o in the network in Fig. P5.49.

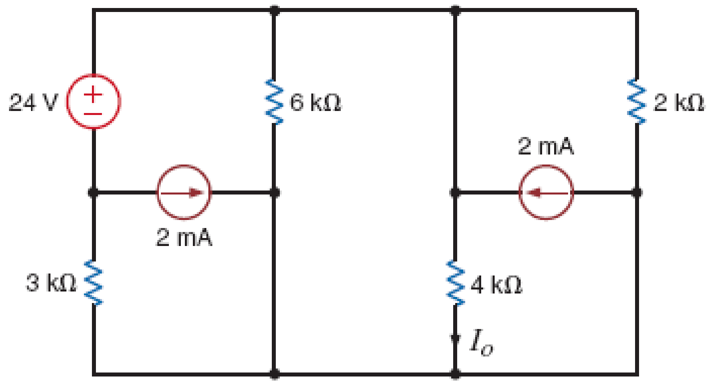
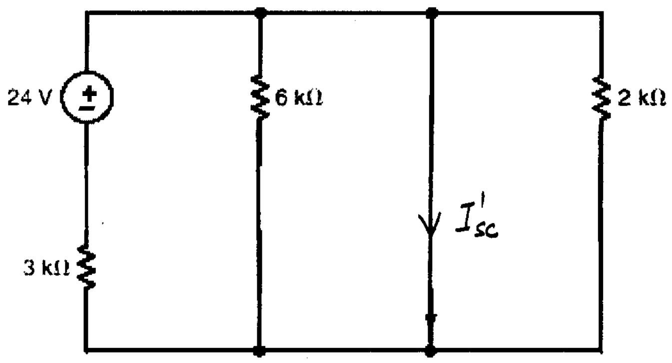
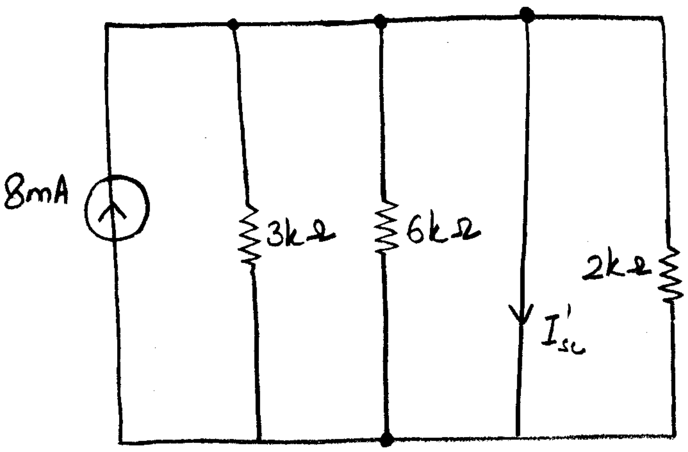


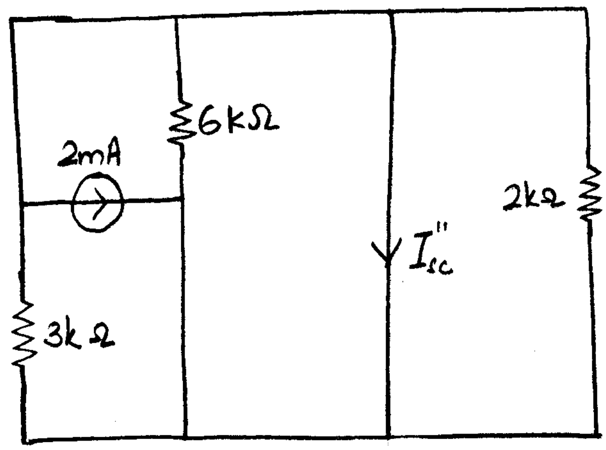
Figure P5.49

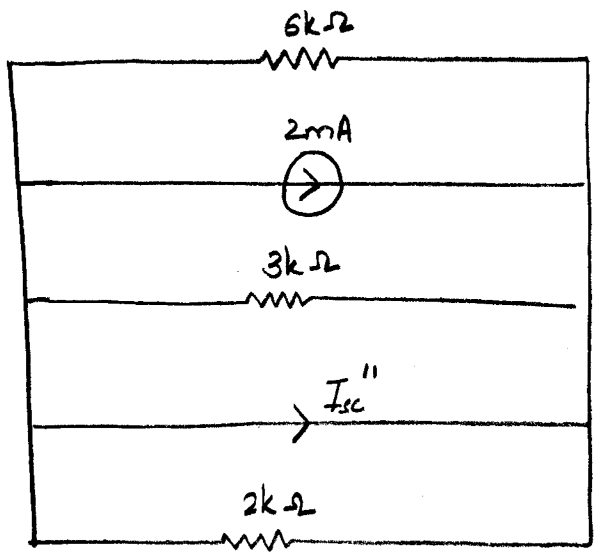
SOLUTION:



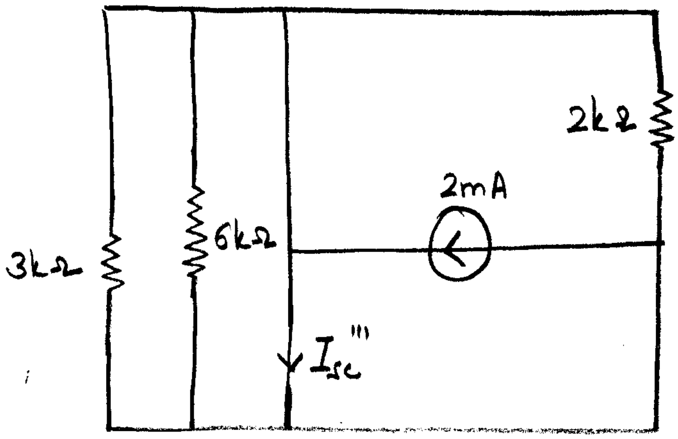


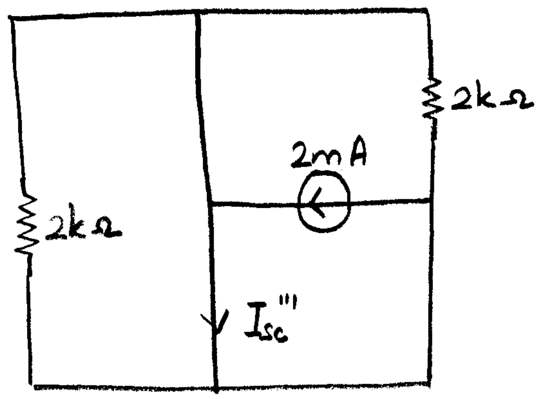
$$I'_{sc} = 8mA$$

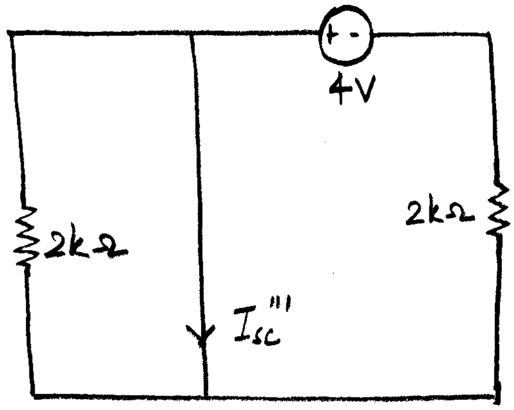




$$I_{sc}'' = -2mA$$

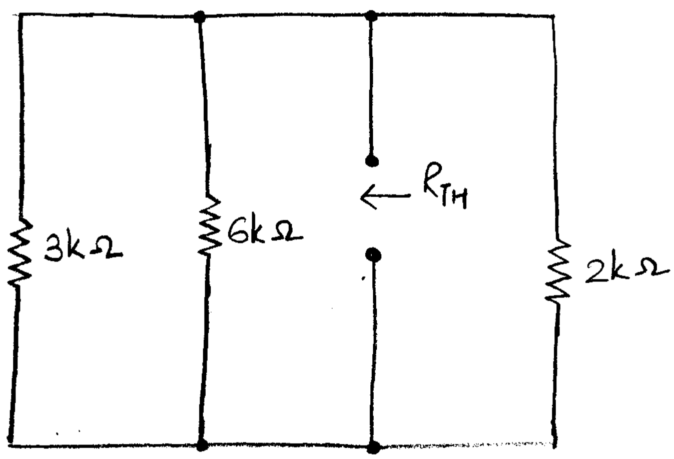




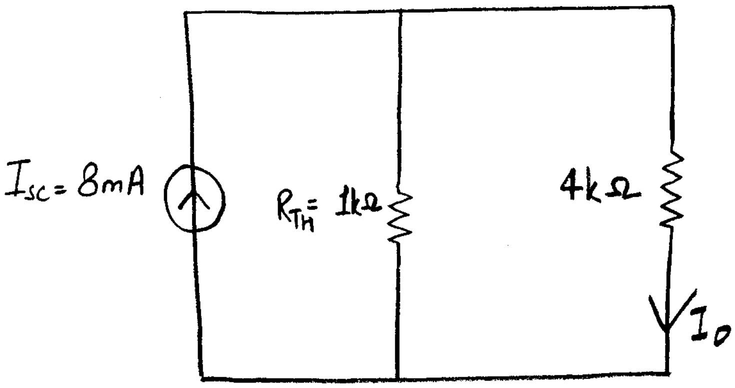


$$I_{sc}''' = \frac{4}{2k} = 2mA$$

$$I_{sc} = 8m - 2m + 2m = 8mA$$



$$R_{TH} = (3k \| 6k) \| 2k = 1k\Omega$$



$$I_o = \left(\frac{1k}{1k + 4k}\right)(8m) = 1.6mA$$

5.50 Find I_o in the network in the Fig. P5.50 using Norton's theorem.

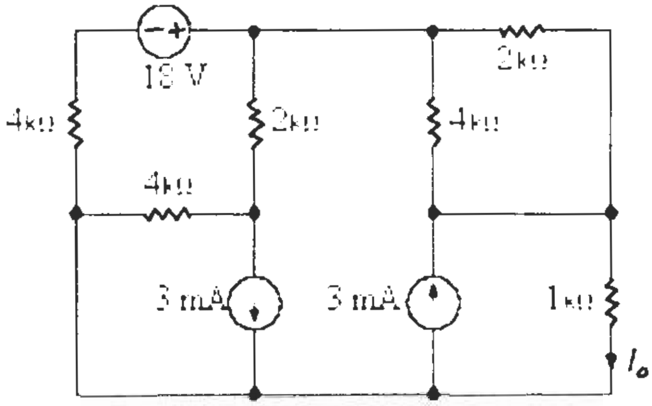
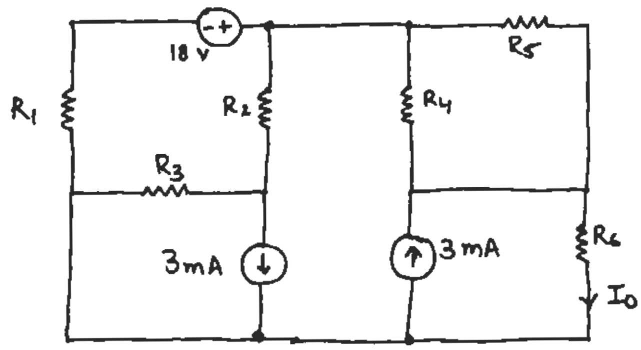
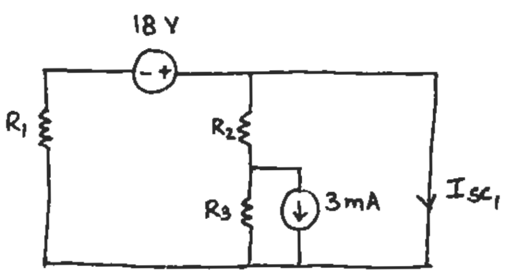


Figure P5.50

Solution: 5.50



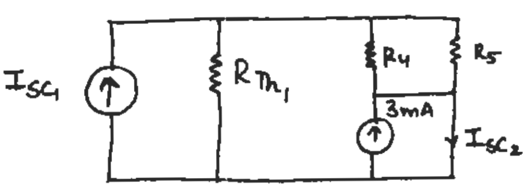
$R_1 = R_3 = R_4 = 4\,k\Omega$; $R_2 = R_5 = 2\,k\Omega$; $R_6 = 1\,k\Omega$



Using Superposition

$$I_{sc_1} = \frac{18}{R_1} - 3 \times 10^{-3} \cdot \frac{R_3}{R_2 + R_3}$$

$$I_{sc_1} = 2.5\ mA$$



$$R_{Th_1} = R_1 \parallel (R_2 + R_3) = 2.4\ k\Omega$$

$$R_A = R_4 \parallel R_5 = \frac{4}{3}\ k\Omega$$

$$I_{sc_2} = 3 \times 10^{-3} + I_{sc_1} \cdot \frac{R_{Th_1}}{R_{Th_1} + R_A}$$

$$I_{SC_2} = 4.61 \text{ mA}$$

$$R_{Th_2} = R_{Th_1} + R_4 = 3.73 \text{ k}\Omega$$

$$I_o = I_{SC_2} \frac{R_{Th_2}}{R_{Th_2} + R_6}$$

$$\boxed{I_o = 3.63 \text{ mA}}$$

5.51 Find V_o in the network in Fig. P5.51 using Thévenin's theorem.

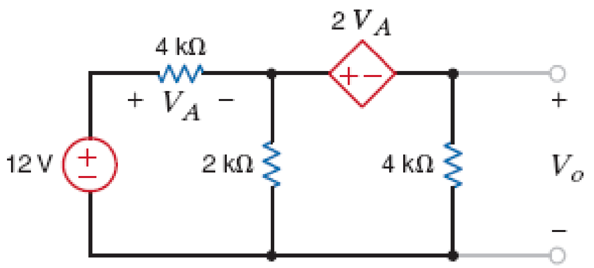
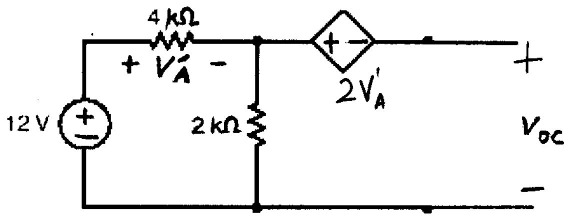


Figure P5.51

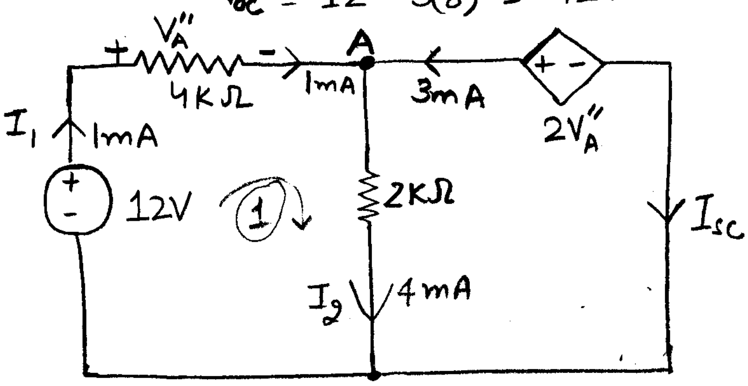
SOLUTION:



$$V_A' = \left(\frac{4k}{4k+2k}\right)(12) = 8V$$

$$12 = V_A' + 2V_A' + V_{oc}$$

$$V_{oc} = 12 - 3(8) = -12V$$



KVL around the outer loop:

$$3V_A'' \quad 12$$

$$V_A'' = 4V$$

$$\frac{V_A''}{4k} = I_1 = 1mA$$

KVL in loop 1:

$$12 = V_A'' + 2k\, I_2$$

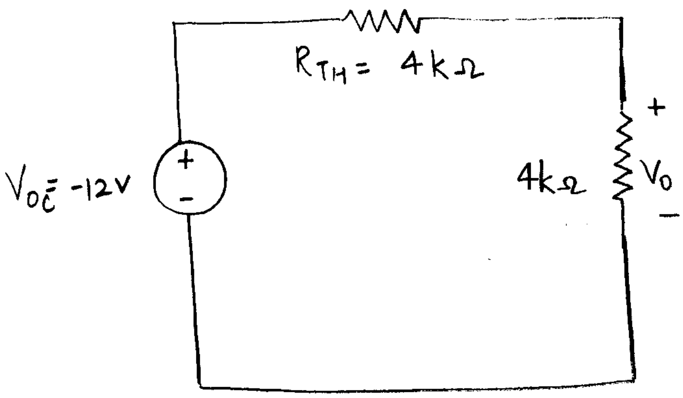
$$I_2 = 4mA$$

KCL at A

$$I_1 - I_{SC} = I_2$$

$$\Rightarrow I_{SC} = I_1 - I_2 = \boxed{-3mA}$$

$$R_{TH} = \frac{-12}{-3m} = 4k\Omega$$



$$V_0 = \left(\frac{4k}{4k + 4k}\right)(-12) = -6V$$

5.52 Use Thévenin's theorem to find V_o in the circuit in Fig. P5.52

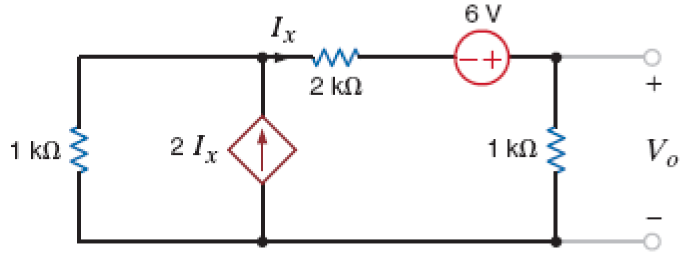
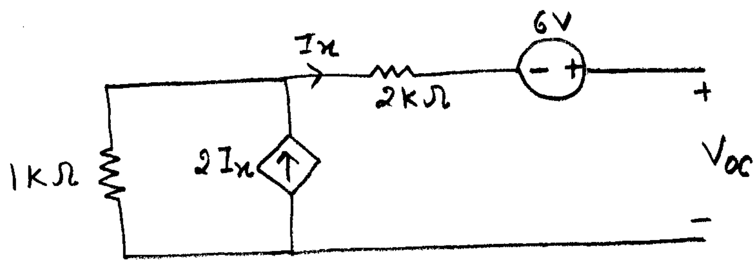
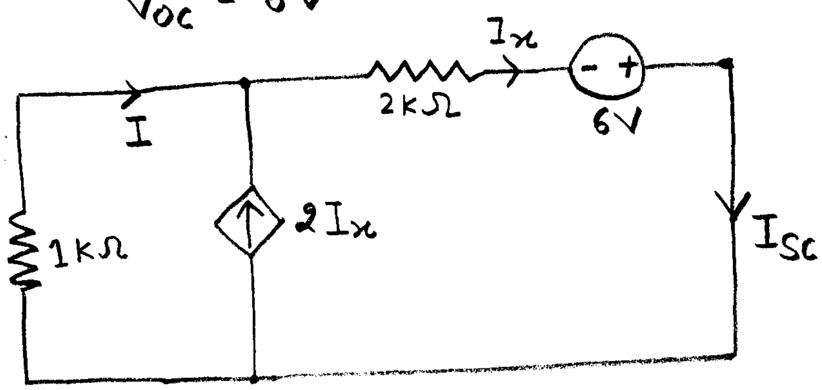


Figure P5.52

SOLUTION:



$$V_{oc} = 6V$$



$$2I_x + I = I_x$$

$$I = -I_x$$

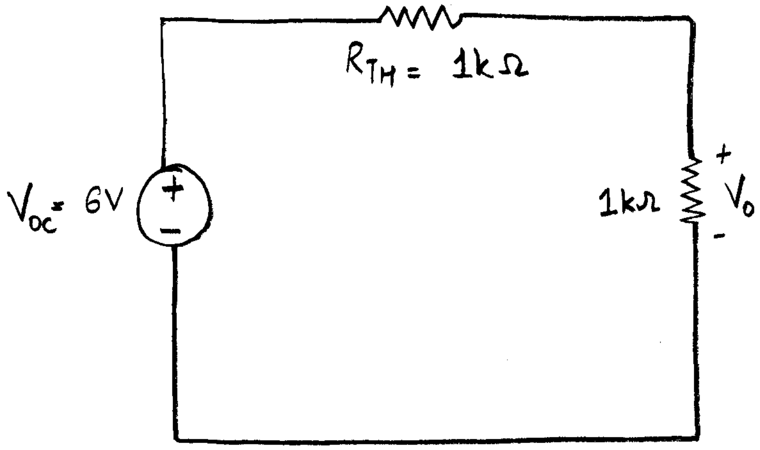
$$6 = I(1k) + I_x(2k)$$

$$6 = -I_x(1k) + I_x(2k)$$

$$I_x = 6mA$$

$$I_{sc} = I_x = 6mA$$

$$R_{TH} = \frac{6}{6m} = 1k\Omega$$



$$V_o = \left(\frac{1k}{1k + 1k}\right)(6) = 3V$$

5.53 In the network in Fig. P5.53, find V_o using Thévenin's theorem.

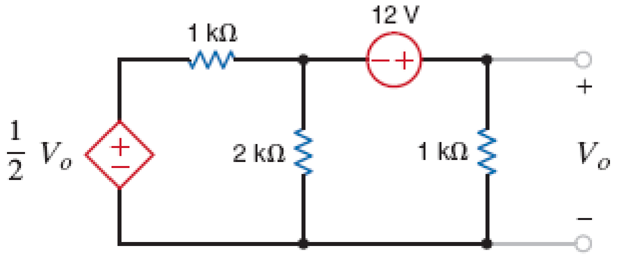
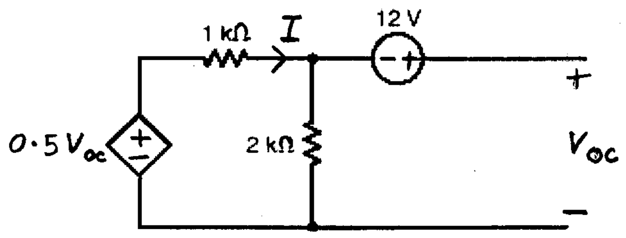


Figure P5.53

SOLUTION:

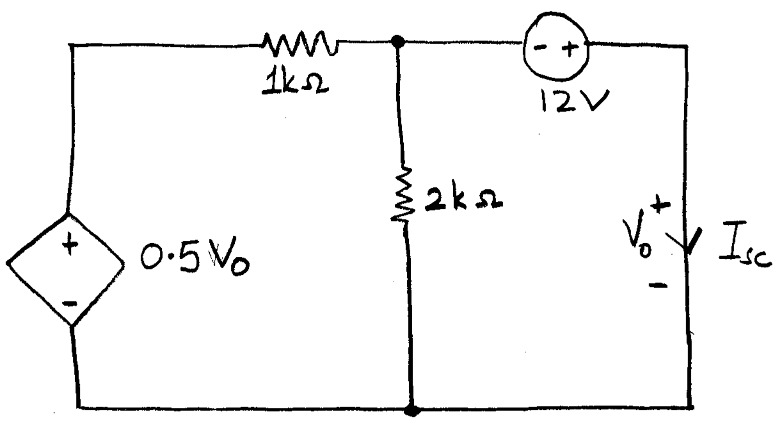


$$3kI = 0.5V_{oc}$$

$$I = 0.167mV_{oc}$$

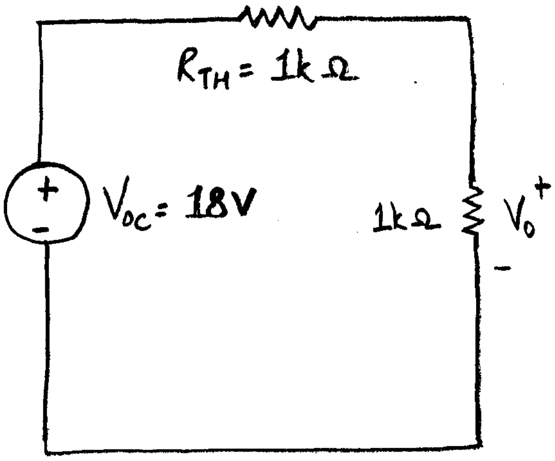
$$V_{oc} = 2k(0.167mV_{oc}) + 12$$

$$V_{oc} = 18V$$



$$I_{sc} = \frac{12}{1k \| 2k} = 18mA$$

$$R_{TH} = \frac{V_{oc}}{I_{sc}} = \frac{18}{18m} = 1k\Omega$$



$$V_0 = \left(\frac{1k}{1k + 1k}\right)(18)$$

$$= 9V$$

5.54 Use Thévenin's theorem to find I_o in the circuit in Fig. P5.54.

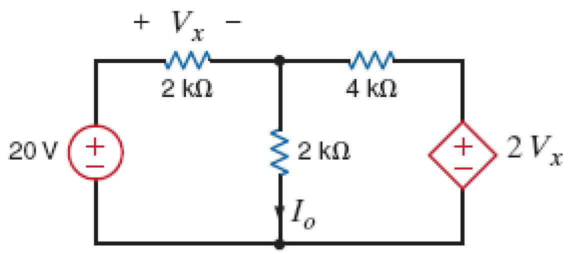
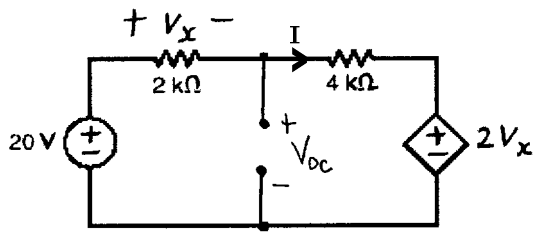


Figure P5.54

SOLUTION:



$$20 = V_x + 4kI + 2V_x$$

$$20 = 3V_x + 4kI$$

$$V_x = \frac{20 - 4kI}{3}$$

$$20 = 2kI + 4kI + 2V_x$$

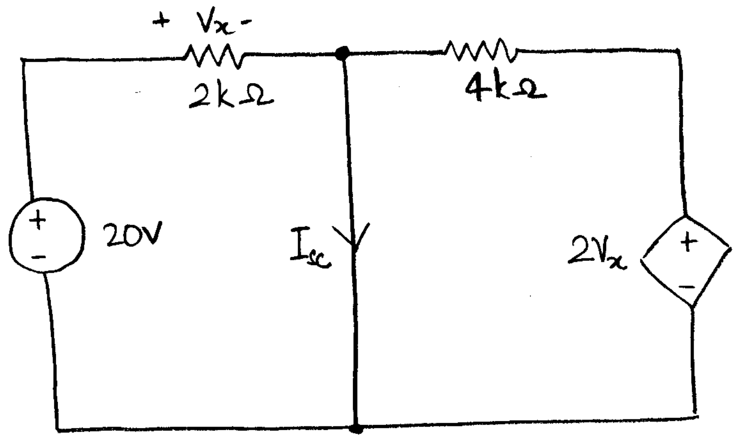
$$20 = 2kI + 4kI + 2\left[\frac{20 - 4kI}{3}\right]$$

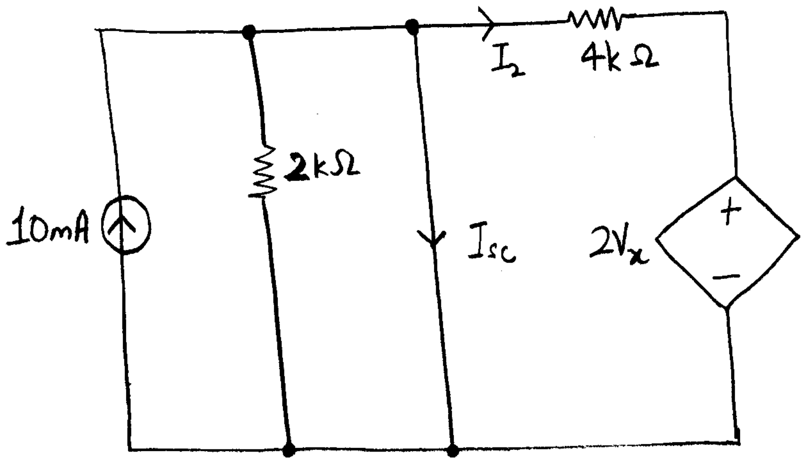
$$20 = 6kI + \frac{40}{3} - \frac{8k}{3}I$$

$$I = 2mA$$

$$V_x = \frac{20 - 4k(2m)}{3} = 4V$$

$$V_{oc} = 4k(2m) + 2(4) = 16V$$





$V_x = 20V$

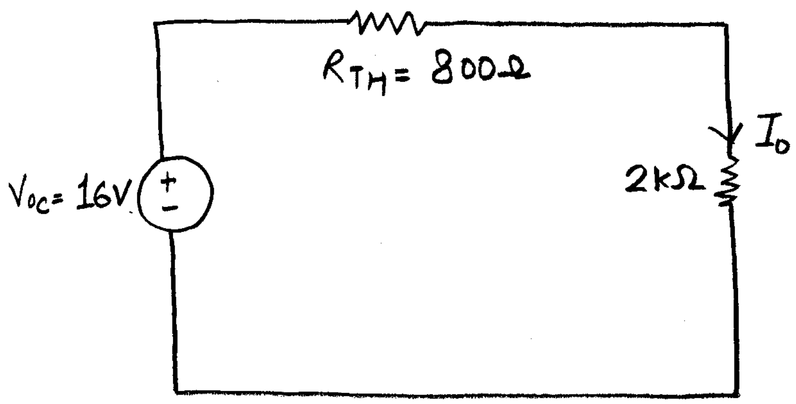
$4kI_2 + 2V_x = 0$

$I_2 = -\frac{2(20)}{4k} = -10mA$

$10m = I_{sc} + I_2$

$I_{sc} = 20mA$

$R_{TH} = \frac{16}{20m} = 800\Omega$



$$I_o = \left(\frac{16k}{2k+800}\right) = 5.71mA$$

5.55 Use Thévenin's theorem to find I_o in the circuit in Fig. P5.55.

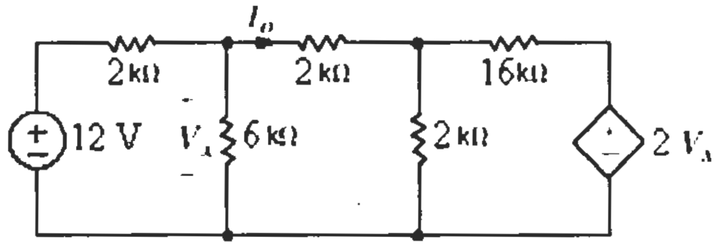
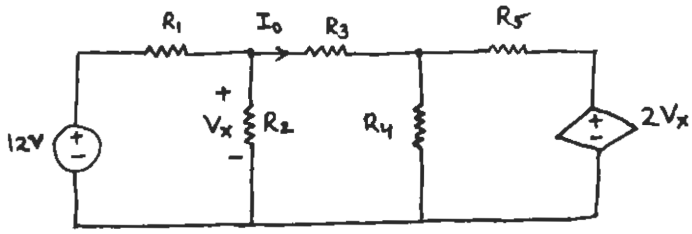
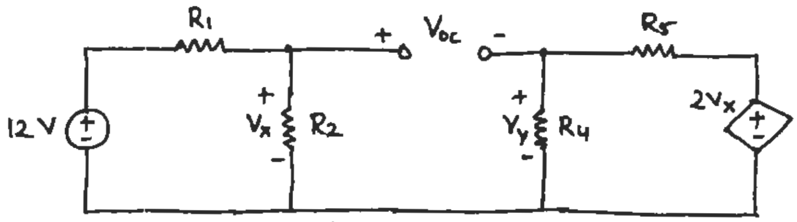


Figure P5.55

Solution: 5.55



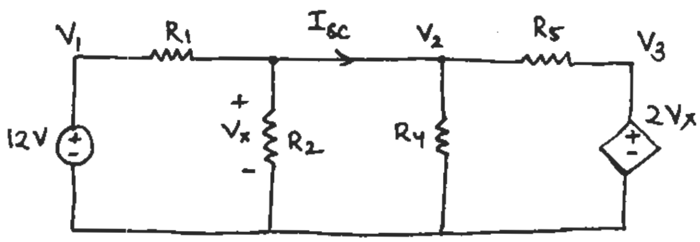
$R_1 = R_3 = R_4 = 2\,k\Omega$; $R_2 = 6\,k\Omega$; $R_5 = 16\,k\Omega$



$$V_x = 12 \cdot \frac{R_2}{R_1 + R_2} = 9\,V$$

$$V_y = 2V_x \cdot \frac{R_4}{R_4 + R_5} = 2\,V$$

$$V_{oc} = V_x - V_y = 7\,V$$



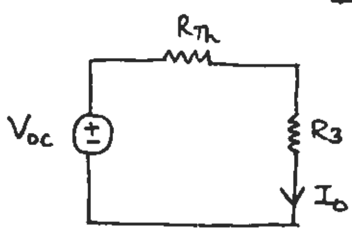
$V_1 = 12\,V$, $V_2 = V_x$, $V_3 = 2V_x = 2V_2$

$$\text{KCL @ } V_2: \quad \frac{V_2 - V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_2}{R_4} + \frac{V_2 - V_3}{R_5} = 0$$

$$V_2 = 5.43\,V$$

$$I_{sc} = \frac{V_1 - V_2}{R_1} - \frac{V_2}{R_2} = 2.38\,mA$$

$$R_{Th} = \frac{V_{oc}}{I_{sc}} = 2.94\ k\Omega$$



$$I_o = \frac{V_{oc}}{R_{Th} + R_3}$$

$$\boxed{I_o = 1.42\ mA}$$

5.56 Use Thévenin's theorem to find V_o in the circuit in Fig. P5.56.

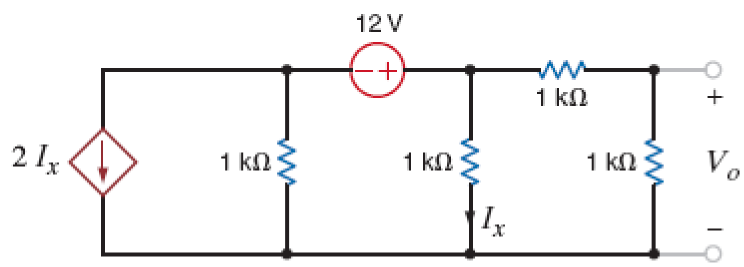
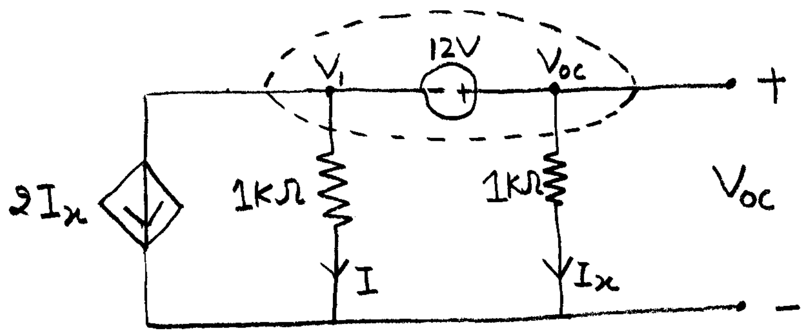


Figure P5.56

SOLUTION:



$$2I_x + \frac{V_1}{1K} + \frac{V_{oc}}{1K} = 0$$

$$V_{oc} - V_1 = 12$$

$$V_{oc} = I_x(1K)$$

$$I_x = \frac{V_{oc}}{1K}$$

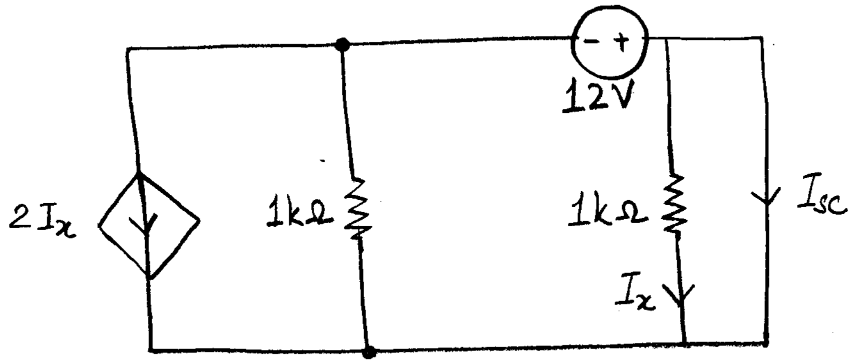
$$2\left(\frac{V_{oc}}{1K}\right) + \frac{V_1}{1K} + \frac{V_{oc}}{1K} = 0$$

$$3V_{oc} + V_1 = 0$$

$$V_{oc} - V_1 = 12$$

$$V_{oc} = 3V$$

$$V_1 = -9V$$

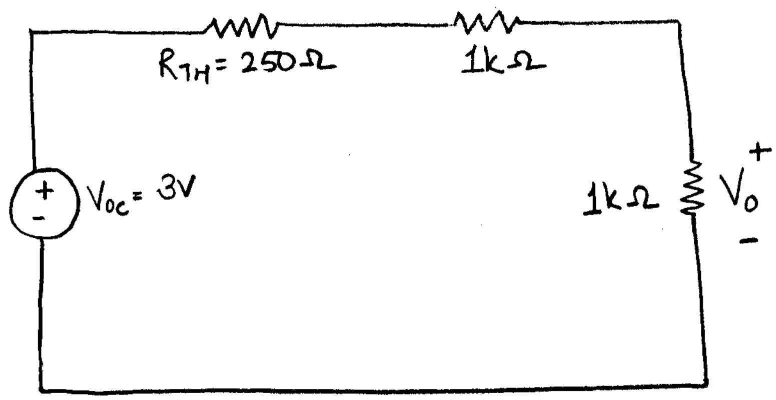


$$I_x = 0$$

$$I_{SC}(1k) = 12$$

$$I_{SC} = 12mA$$

$$R_{TH} = \frac{3}{12m} = 250\Omega$$



$$V_o = \left(\frac{1k}{1k + 1k + 250}\right)(3) = 1.33V$$

5.57 Find V_o in the network in Fig. P5.57 using Thévenin's theorem.

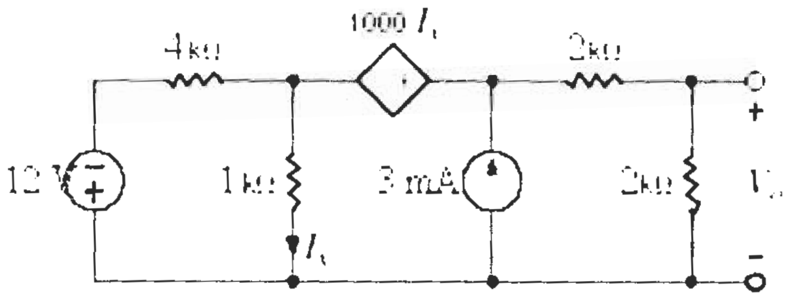
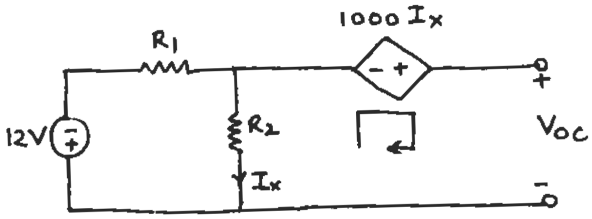


Figure P5.57

Solution: 5.57



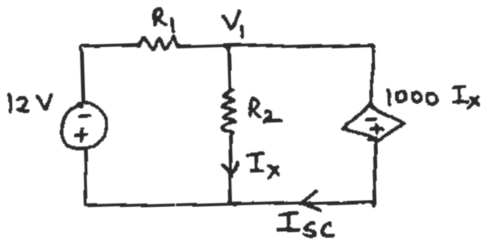
$R_1 = 4\,k\Omega$, $R_2 = 1\,k\Omega$

$R_3 = R_4 = 2\,k\Omega$

$$I_x = \frac{-12}{R_1 + R_2} = -2.4\text{ mA}$$

$$\text{KVL}: \; -I_x R_2 - 1000 I_x + V_{oc} = 0$$

$$V_{oc} = -4.8\text{ V}$$

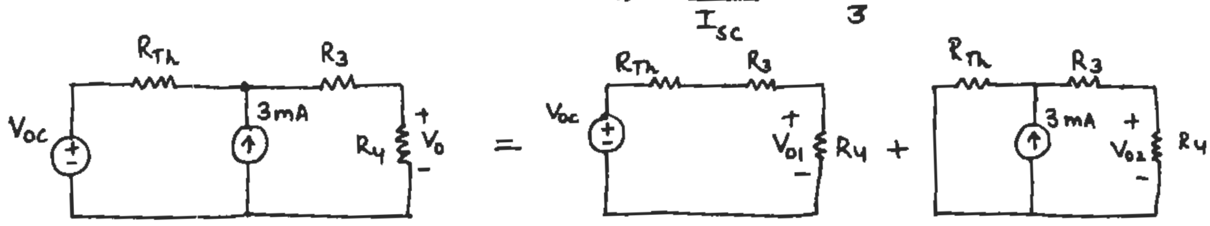


$$I_x = \frac{V_1}{R_2} \qquad V_1 = 1000\, I_x$$

$$I_x = 0\text{ mA} \Rightarrow V_1 = 0\text{ V}$$

$$I_{sc} = \frac{-12}{R_1} = -3\text{ mA}$$

$$R_{Th} = \frac{V_{oc}}{I_{sc}} = \frac{-4.8}{3} = 1.6\,k\Omega$$



$$V_o = V_{o1} + V_{o2}$$

$$= V_{oc} \cdot \frac{R_4}{R_3 + R_4 + R_{Th}} + 3\times10^{-3} \cdot \frac{R_{Th}}{R_3 + R_4 + R_{Th}} \times R_4$$

$$= -1.71 + 1.71$$

$$\boxed{V_o = 0\text{ V}}$$

5.58 Use Norton's theorem to find V_o in the network in Fig. P5.58.

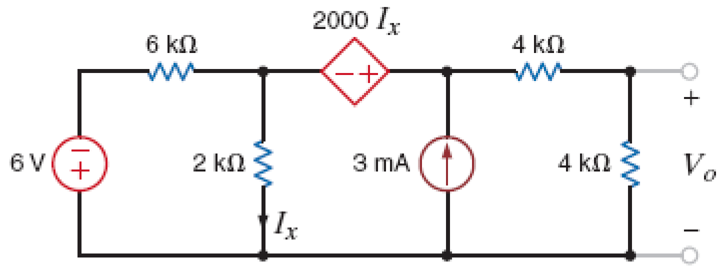
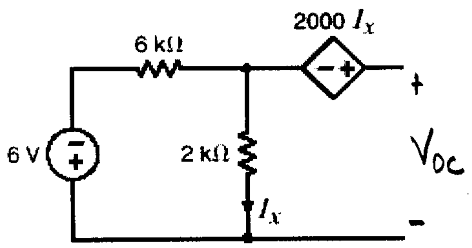


Figure P5.58

SOLUTION:



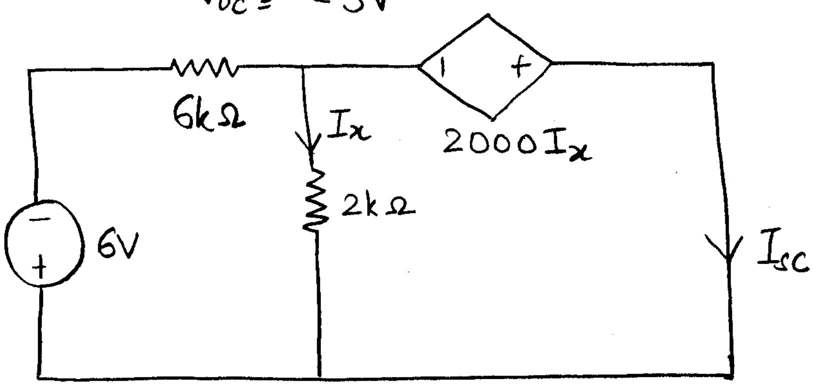
$$-6 = (6k + 2k)\, I_x$$

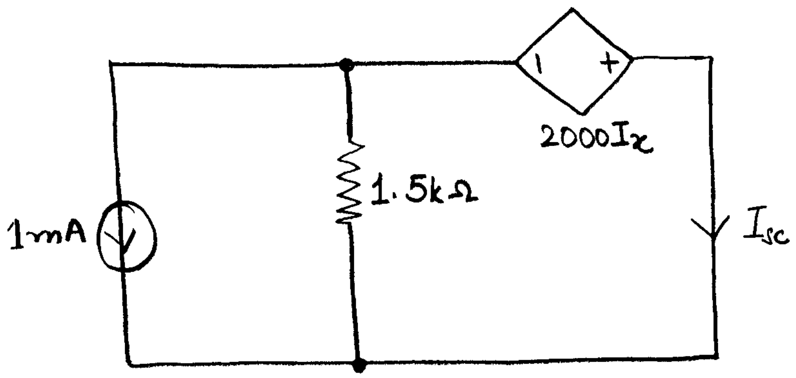
$$I_x = \frac{-6}{8k} = -0.75\,mA$$

$$V_{oc} = 2000\, I_x + 2k\, I_x$$

$$V_{oc} = 2000(-0.75m) + 2k(-0.75m)$$

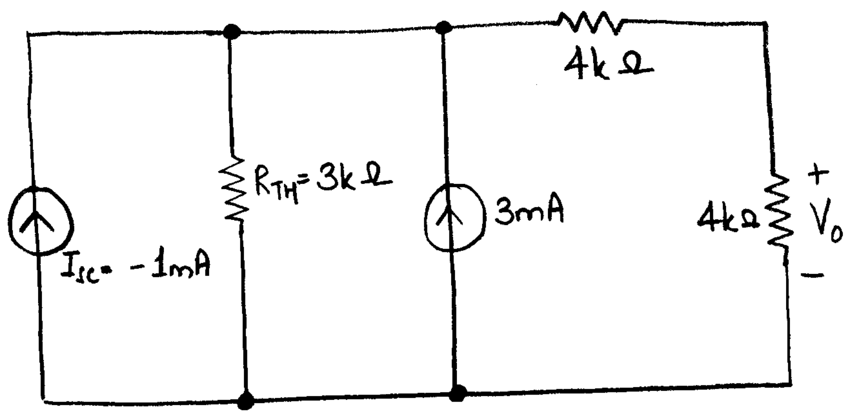
$$V_{oc} = -3V$$

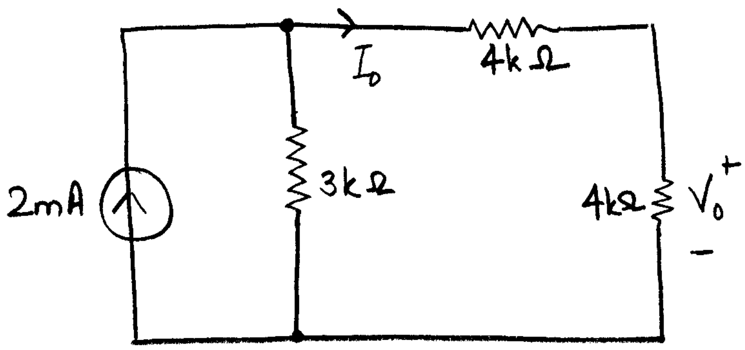




$$I_{sc} = -1mA$$

$$R_{TH} = \frac{-3}{-1m} = 3k\Omega$$





$$I_o = \left(\frac{3k}{3k + 4k + 4k} \right)(2m)$$

$$= 0.545mA$$

$$V_o = (0.545m)(4k)$$

$$= 2.18V$$

5.59 Find V_o in the circuit in Fig. P5.59 using Thévenin's theorem.

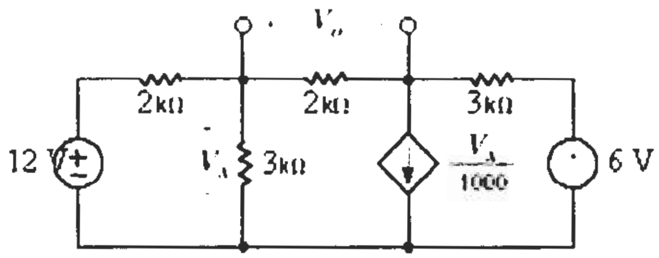
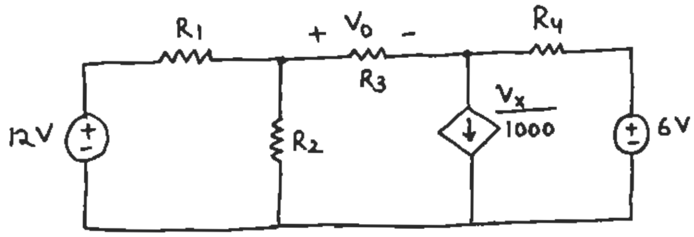
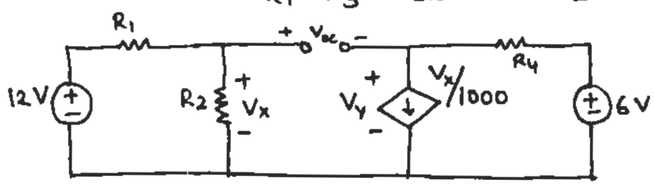


Figure P5.59

Solution: 5.59



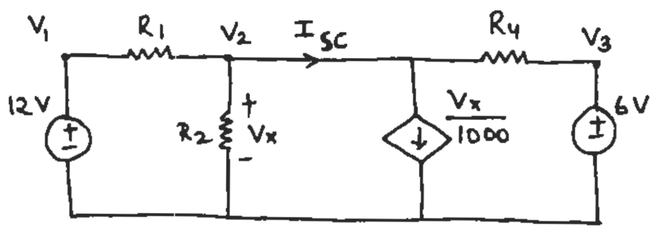
$R_1 = R_3 = 2k\Omega \qquad R_2 = R_4 = 3k\Omega$



$$V_x = 12 \cdot \frac{R_2}{R_1 + R_2} = 7.2\ V$$

$$V_y = 6 - \frac{V_x}{1000} R_4 = -15.6\ V$$

$$V_{oc} = V_x - V_y = 22.8\ V$$



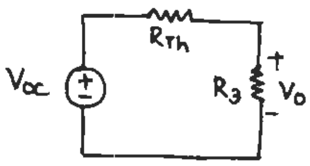
$$V_1 = 12\ V, \quad V_3 = 6\ V, \quad V_2 = V_x$$

KCL @ V_2 :
$$\frac{V_2 - V_1}{R_1} - \frac{V_2}{R_2} + \frac{V_x}{1000} + \frac{V_2 - V_3}{R_4} = 0$$

$$V_2 = 3.69\ V$$

$$I_{sc} = \frac{V_1 - V_2}{R_1} - \frac{V_2}{R_2} = 2.93\ mA$$

$$R_{Th} = \frac{V_{oc}}{I_{sc}} = 7.78\ k\Omega$$



$$V_o = V_{oc} \cdot \frac{R_3}{R_3 + R_{Th}}$$

$$\boxed{V_o = 4.66 \text{ V}}$$

5.60 Find V_o in the network in Fig. P5.60 using Norton's theorem.

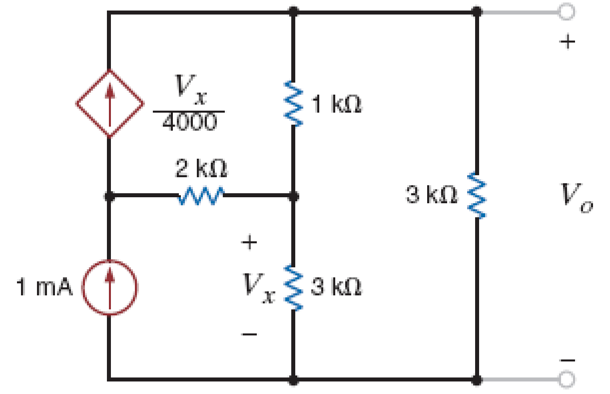
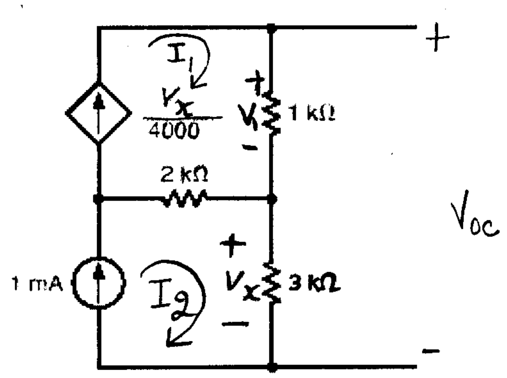


Figure P5.60

SOLUTION:

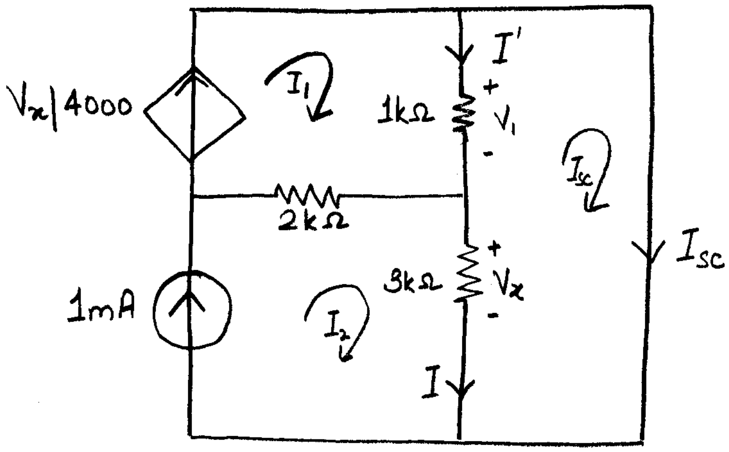


$$V_1 = \frac{V_x}{4000}(1k) = \frac{V_x}{4}$$

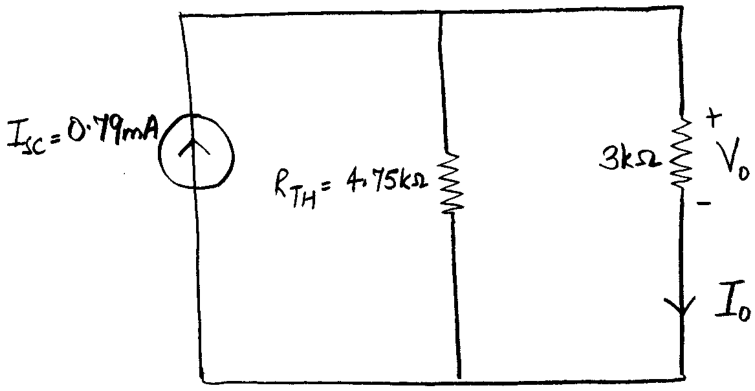
$$V_x = 3k(1m) = 3V$$

$$V_1 = \frac{3}{4}V$$

$$V_{oc} = V_x + V_1 = 3 + \frac{3}{4} = \frac{15}{4}\ V$$



$$I_2 = 1mA$$
$$I_1 = \frac{V_x}{4000}$$
$$I + I_{sc} = I_2$$
$$I = I_2 - I_{sc}$$
$$V_x = 3k(I_2 - I_{sc})$$
$$I' = I_1 - I_{sc}$$
$$V_1 = 1k(I_1 - I_{sc})$$
$$V_1 + V_x = 0$$
$$1k(I_1 - I_{sc}) + 3k(I_2 - I_{sc}) = 0$$
$$1kI_1 - 4kI_{sc} = -3$$
$$4kI_1 = 3k(I_2 - I_{sc})$$
$$4kI_1 + 3kI_{sc} = 3$$
$$I_1 = 0.16mA$$
$$I_{sc} = 0.79mA$$
$$R_{TH} = \frac{V_{oc}}{I_{sc}}$$
$$= \frac{3.75}{0.79m}$$
$$= 4.75k\Omega$$



$$I_0 = \left(\frac{4.75k}{4.75k + 3k}\right)(0.79m) = 0.484mA$$

$$V_0 = (0.484m)(3k)$$

$$= 1.45V$$

5.61 Find I_o in the network in Fig. P5.61 using Thévenin's theorem.

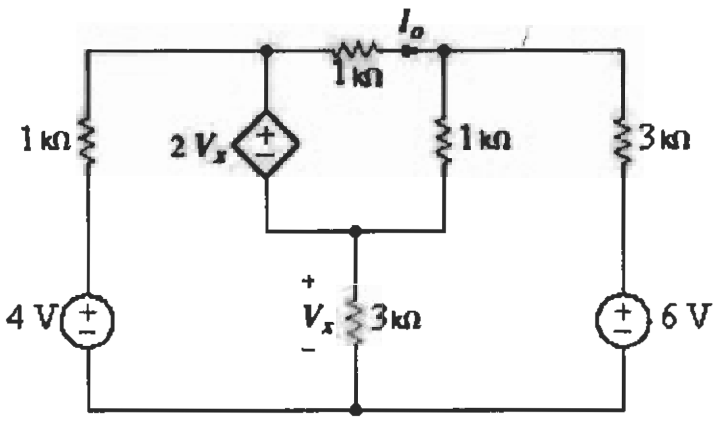
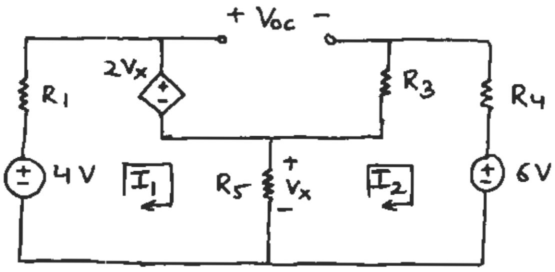


Figure P5.61

Solution: 5·61



$R_1 = R_2 = R_3 = 1\,k\Omega$, $R_4 = R_5 = 3\,k\Omega$

KVL @ I_1: $-4 + I_1 R_1 + 2V_x + (I_1 - I_2) R_5 = 0$

$$-4 + 10^3 I_1 + 2(I_1 - I_2)\,3 \times 10^3 + (I_1 - I_2)\,3 \times 10^3 = 0$$

$$I_1 + 9(I_1 - I_2) = 4 \times 10^{-3}$$

$$10 I_1 - 9 I_2 = 4 \times 10^{-3} \quad \text{——} \quad (1)$$

KVL @ I_2: $(I_2 - I_1) R_5 + I_2 R_3 + I_2 R_4 + 6 = 0$

$$(I_2 - I_1)\,3 \times 10^3 + I_2 \times 10^3 + I_2 \times 3 \times 10^3 + 6 = 0$$

$$7 I_2 - 3 I_1 = -6 \times 10^{-3} \quad \text{——} \quad (2)$$

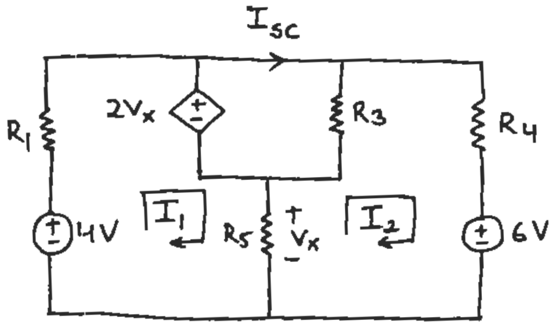
From equations (1) and (2) we get

$I_1 = -0.61$ mA , $I_2 = -1.12$ mA

$$V_x = (I_1 - I_2) R_5 = (-0.61 + 1.12)3$$

$$= 1.52\text{ V}$$

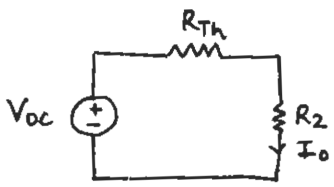
$$V_{oc} = 2V_x + R_3 I_2 = 3.04 - 1.12 = 1.92\text{ V}$$



$$2V_x = (I_{sc} - I_2)\, R_3$$

$$2(1.52) = (I_{sc} \times 1 \times 10^3) + 1.12$$

$$I_{sc} = 1.92 \text{ mA}$$



$$R_{Th} = \frac{V_{oc}}{I_{sc}} = \frac{1.92}{1.92} = 1\,k\Omega$$

$$I_o = \frac{V_{oc}}{R_2 + R_{Th}} = \frac{1.92}{1+1} = 0.96 \text{ mA}$$

$$\boxed{I_o = 0.96 \text{ mA}}$$

5.62 Use Thévenin's theorem to find the power supplied by the 2-V source in the circuit in Fig. P5.62.

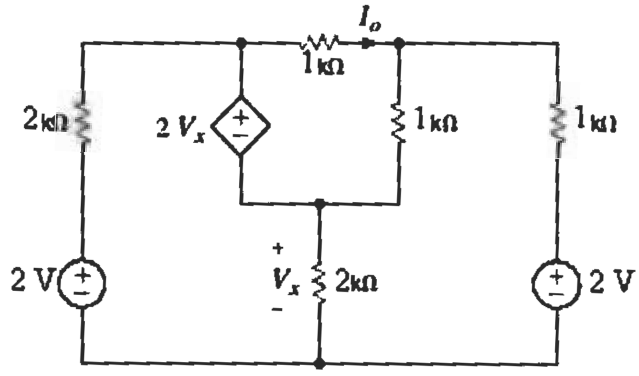
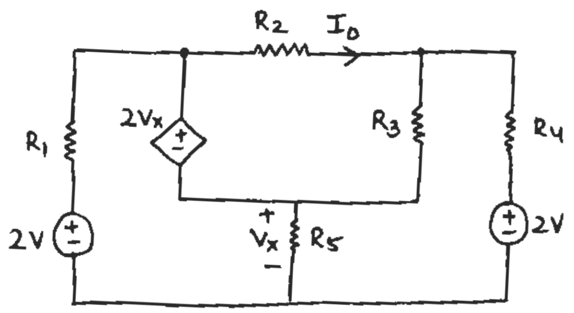
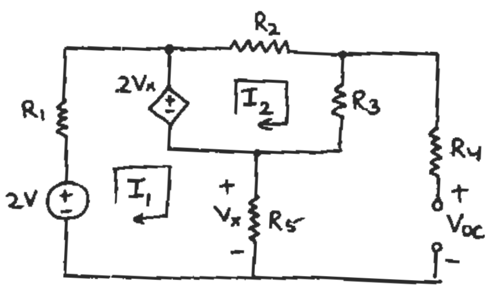


Figure P5.62

Solution: 5.62



$R_1 = R_5 = 2k\Omega$, $R_2 = R_3 = R_4 = 1\,k\Omega$



$V_x = I_1 R_5$

KVL @ I_1 : $-2 + I_1 R_1 + 2V_x + I_1 R_5 = 0$

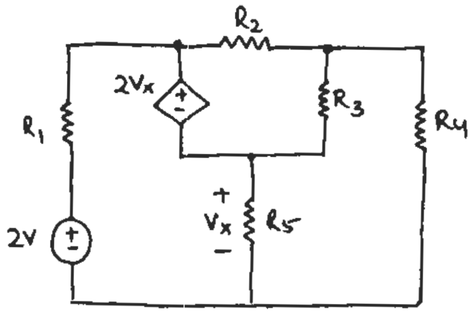
$I_1 = 0.25\text{ mA}$

KVL @ I_2 : $-2V_x + I_2(R_2 + R_3) = 0$

$I_2 = 0.5\text{ mA}$

$V_{oc} = I_2 R_3 + I_1 R_5$

$V_{oc} = 1\text{ V}$

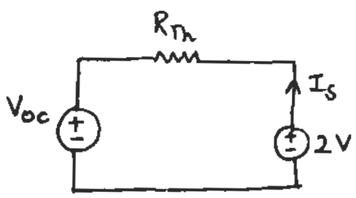


KVL @ I_{SC}:

$$I_{SC}(R_5+R_3+R_4)-I_1R_5-I_2R_3=0$$

$$I_{SC} = 0.25 \text{ mA}$$

$$R_{Th} = \frac{V_{OC}}{I_{SC}} = 4\text{ k}\Omega$$



$$I_S = \frac{2-V_{OC}}{R_{Th}} = 0.25 \text{ mA}$$

$$P_{2V} = 2I_S$$

$$\boxed{P_{2V} = 0.50 \text{ mW}}$$

5.63 Find V_o in the circuit in Fig. P5.63 using Thévenin's theorem.

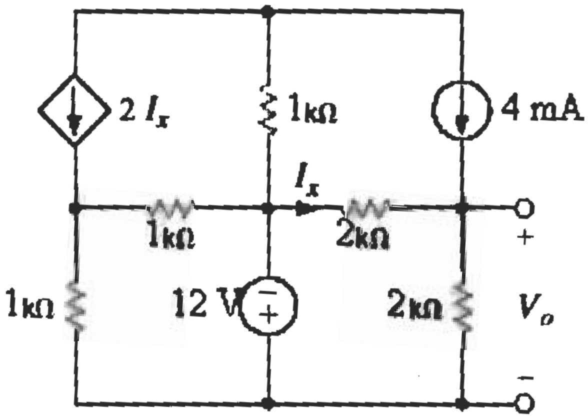
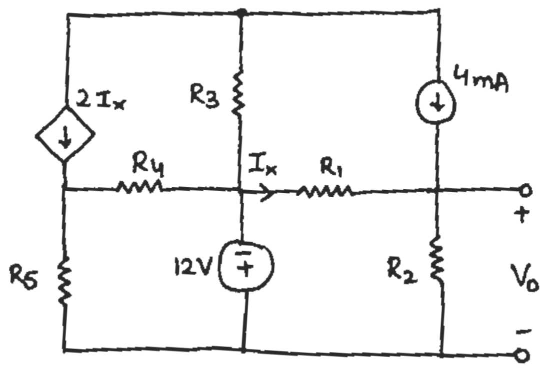
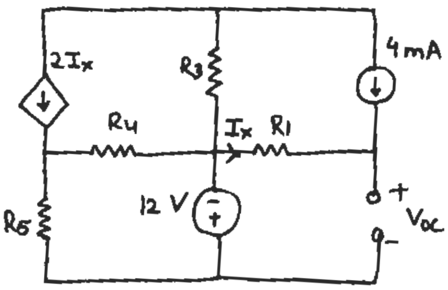


Figure P5.63

Solution: 5.63

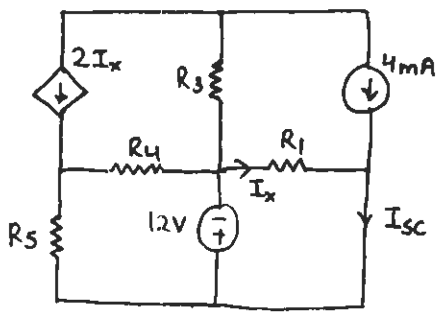


$R_1 = R_2 = 2 \times 10^3\ \Omega\ ,\ R_3 = R_4 = R_5 = 1\,k\Omega$



$12 - (4 \times 10^{-3})R_1 + V_{oc} = 0$

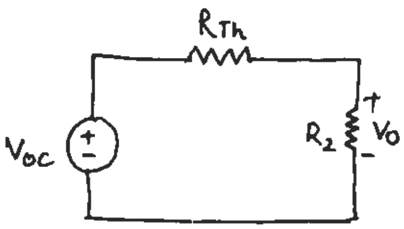
$V_{oc} = -4\,V$



$$I_x = \frac{-12}{R_1} = -6\,mA$$

$$I_{sc} = 4\times10^{-3} + I_x = -2\,mA$$

$$R_{Th} = \frac{V_{oc}}{I_{sc}} = 2\,k\Omega$$



$$V_o = V_{oc}\,\frac{R_2}{R_2 + R_{Th}}$$

$$\boxed{V_o = -2.00\,V}$$

5.64 Find V_o in the network in Fig. P5.64 using Thévenin's theorem.

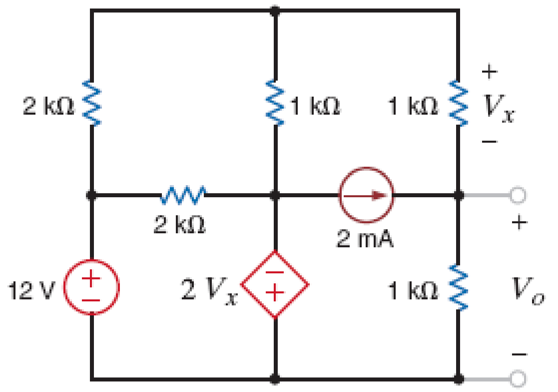
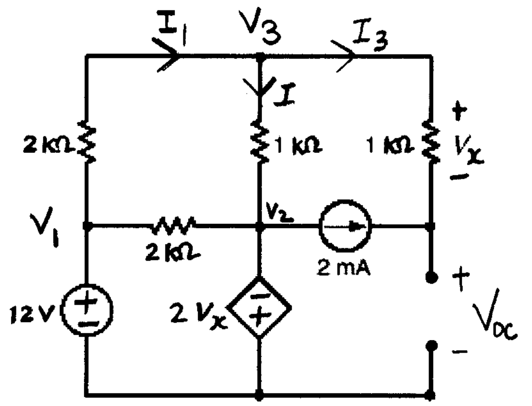


Figure P5.64

SOLUTION:



$$V_1 = 12\text{V}$$

$$V_2 = -2V_x$$

$$V_x = V_3 - V_{oc}$$

$$I_1 = I + I_3$$

$$\frac{V_1 - V_3}{2k} = \frac{V_3 - V_2}{1k} + \frac{V_3 - V_{oc}}{1k}$$

$$-V_1 - 2V_2 + 5V_3 - 2V_{oc} = 0$$

$$I_3 = -2\text{mA}$$

$$\frac{V_3 - V_{oc}}{1k} = -2m$$

$$V_3 - V_{oc} = -2$$

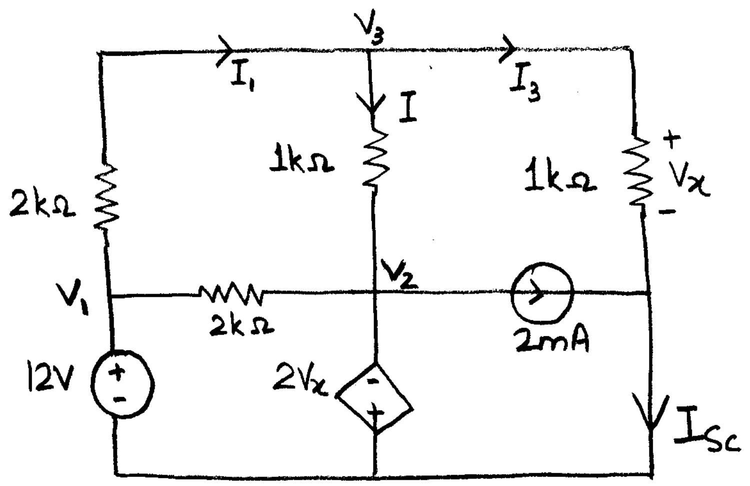
$$V_2 = -2V_3 + 2V_{oc}$$

$$-12 - 2[-2V_3 + 2V_{oc}] + 5V_3 - 2V_{oc} = 0$$

$$9V_3 - 6V_{oc} = 12$$

$$V_3 = 8V$$

$$V_{oc} = 10V$$



$$V_3 = V_x$$

$$V_1 = 12V$$

$$V_2 = -2V_x$$

$$\frac{V_1 - V_3}{2k} = \frac{V_3 - V_2}{1k} + \frac{V_3}{1k}$$

$$V_1 + 2V_2 - 5V_3 = 0$$

$$-12 + 2[-2V_x] - 5V_x = 0$$

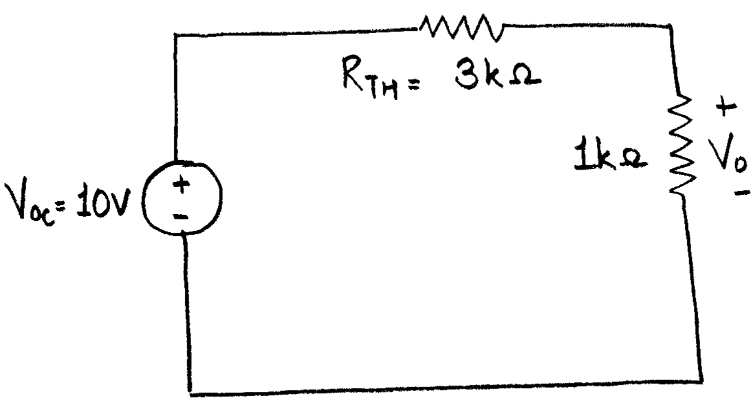
$$V_x = \frac{4}{3} V$$

$$V_3 = V_x = \frac{4}{3} V$$

$$2m + \frac{V_3}{1k} = I_{sc}$$

$$I_{sc} = 3.33 mA$$

$$R_{TH} = \frac{10}{3.33m} = 3k\,\Omega$$



$$V_0 = \left(\frac{1k}{1k+3k}\right)(10) = 2.5V$$

5.65 Find V_o in the network of Fig. P5.65 using Thévenin's theorem.

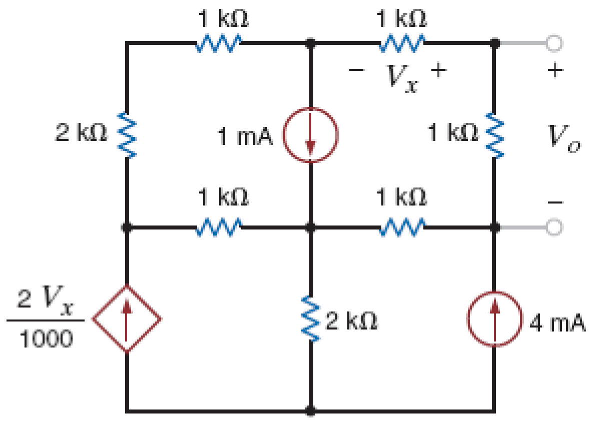
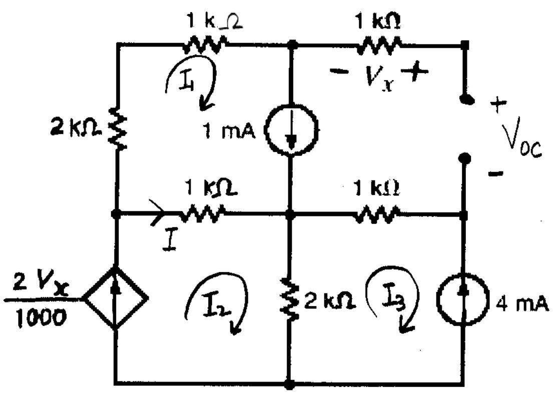


Figure P5.65

SOLUTION:



$$I_1 = 1mA$$

$$I_2 = \frac{V_x}{500}$$

$$I_3 = -4mA$$

$$V_x = 0V$$

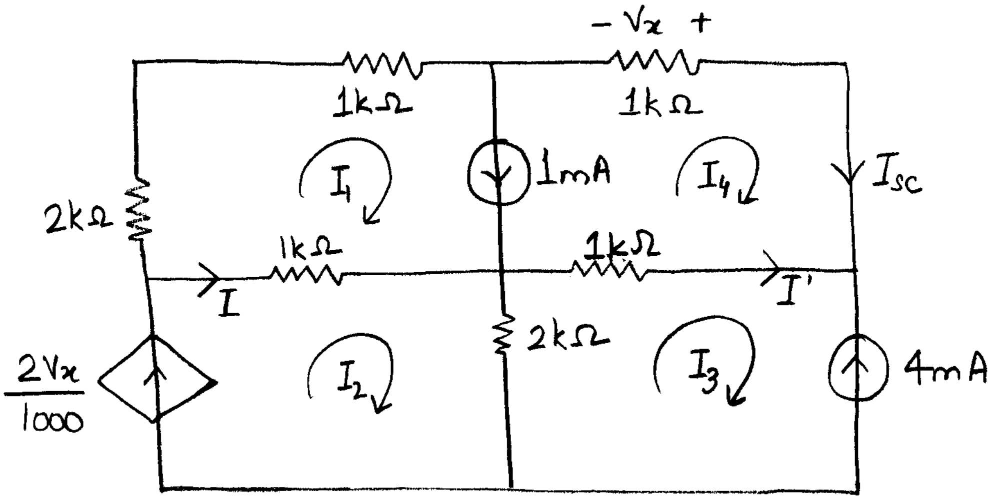
$$I_2 = 0A$$

$$I_1 + I = 0$$

$$I = -1mA$$

$$V_{oc} + 2kI_1 + 1kI_1 = 1kI_3 + 1kI$$

$$V_{oc} = -4 - 1 - 1 - 2 = -8V$$



$$I_2 = \frac{V_x}{500}$$

$$I_3 = -4mA$$

$$I_4 = I_{sc}$$

$$V_x = -1k\,I_4$$

$$I + I_1 = \frac{V_x}{500}$$

$$I' + I_4 = I_3$$

$$I' = I_3 - I_4$$

$$I_1 = 1m + I_4$$

$$3k\,I_1 + 1k\,I_4 + 1k(I_4 - I_3) + 1k(I_1 - I_2) = 0$$

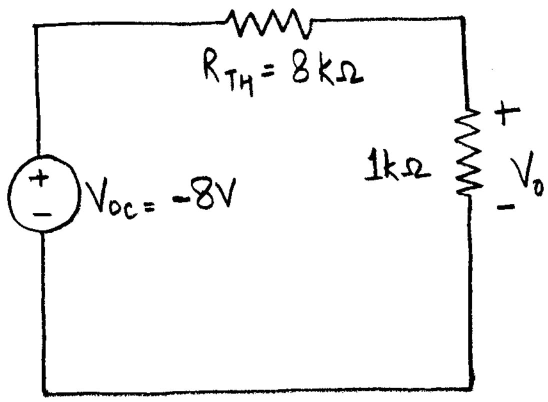
$$4k\,I_1 + 4k\,I_4 = -4$$

$$I_1 = 0A$$

$$I_4 = -1mA$$

$$I_{sc} = -1mA$$

$$R_{TH} = \frac{-8}{-1m} = 8k\Omega$$



$$V_o = \left(\frac{1k}{1k+8k}\right)(-8)$$

$$= -0.889V$$

5.66 Use Thévenin's theorem to find I_o in the network in Fig. P5.66.

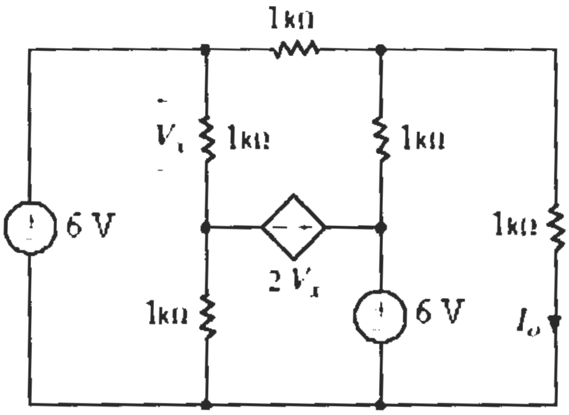
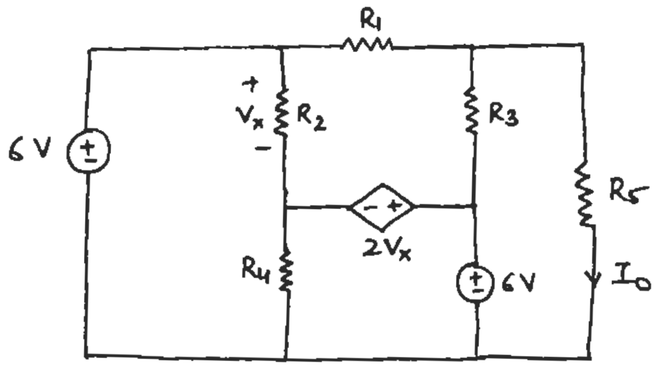
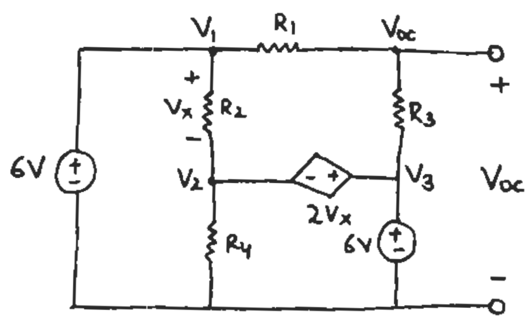


Figure P5.66

Solution: 5.66





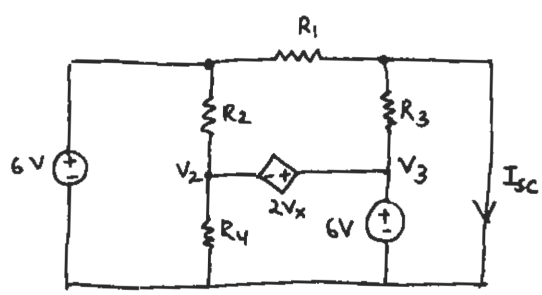
$R_1 = R_2 = R_3 = R_4 = R_5 = 1k\Omega$

$V_1 = 6V, V_3 = 6V, \quad V_x = V_1 - V_2$

$V_3 - V_2 = 2V_x$

KCL @ V_{oc}: $\dfrac{V_{oc} - V_1}{R_1} + \dfrac{V_{oc} - V_3}{R_3} = 0$

$V_{oc} = 6V$

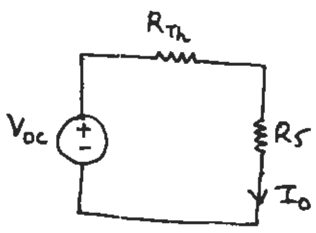


$V_1 = 6V, V_3 = 6V, \quad V_x = V_1 - V_2$

$V_3 - V_2 = 2V_x$

$\dfrac{V_1}{R_1} + \dfrac{V_3}{R_3} = I_{sc}$

$I_{sc} = 12 \text{ mA}$



$$R_{Th} = \frac{V_{oc}}{I_{sc}} = 0.5\,k\Omega$$

$$I_o = \frac{V_{oc}}{R_{Th} + R_5}$$

$$\boxed{I_o = 4.00\ mA}$$

5.67 Use Thévenin's theorem to find V_o in the network in Fig. P5.67.

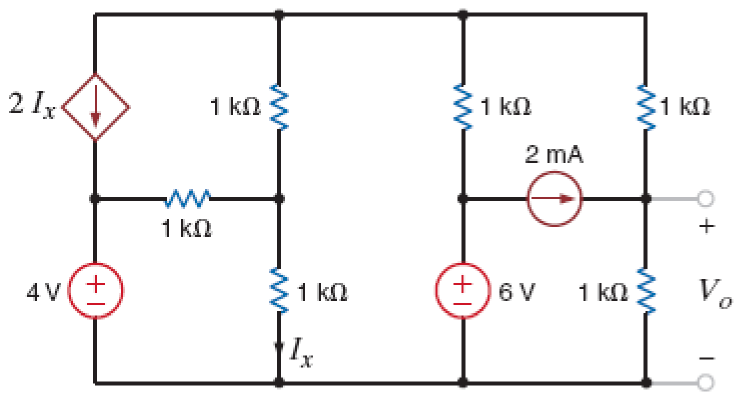
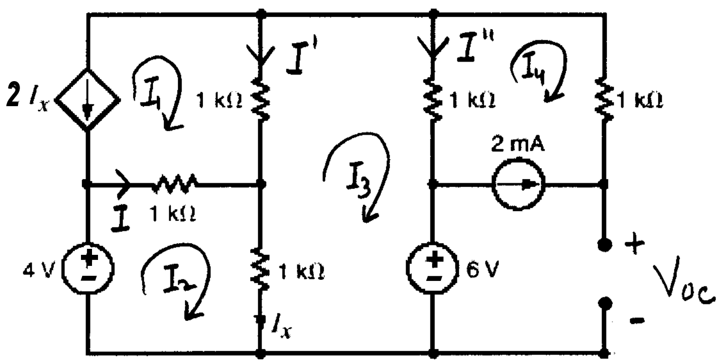


Figure P5.67

SOLUTION:



$$I_1 = -2I_x$$

$$I_x = I_2 - I_3$$

$$I_4 = -2mA$$

$$I_2 = I + I_1$$

$$I = I_2 - I_1$$

$$4 = 1k\,I + 1k\,I_x$$

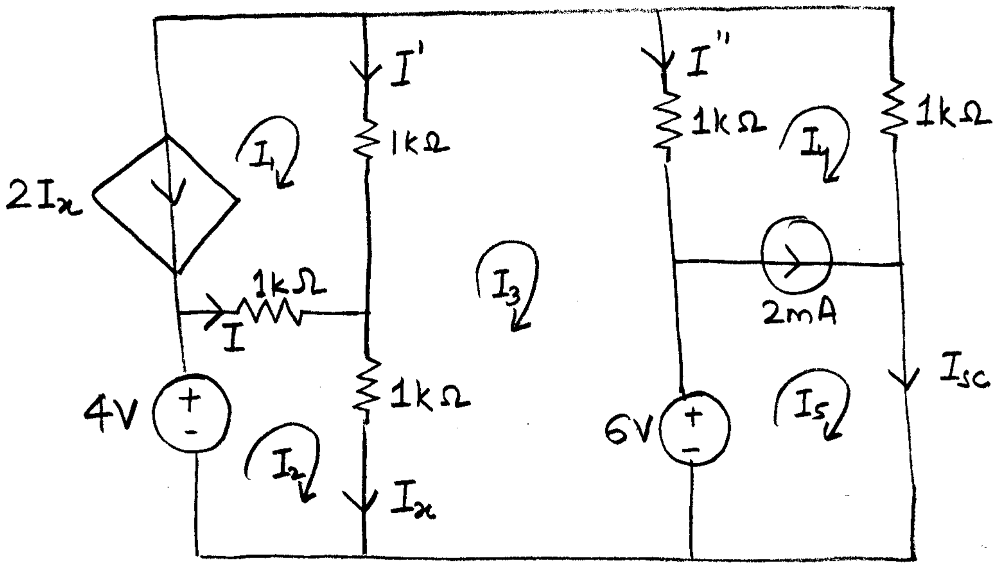
$$4 = 1k(I_2 - I_1) + 1k(I_2 - I_3)$$

$$I' + I_3 = I_1$$

$$I' = I_1 - I_3$$

$$I_3 = I'' + I_4$$

$$I'' = I_3 - I_4$$
$$-6 = -1k\,I_x - 1k\,I' + 1k\,I''$$
$$-6 = -1k\,I_1 - 1k\,I_2 + 3k\,I_3 - 1k\,I_4$$
$$6 = -1k\,I'' + 1k\,I_4 + V_{oc}$$
$$V_{oc} = 4.86V$$

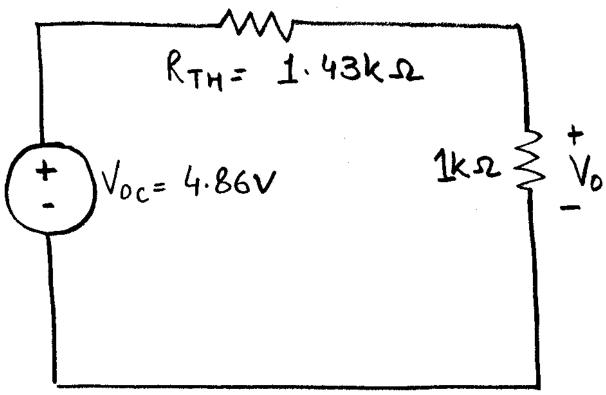


$$I_1 = -2I_x$$
$$I_x = I_2 - I_3$$
$$I_5 - I_4 = 2m$$
$$I = I_2 - I_1$$
$$I' = I_1 - I_3$$
$$I'' = I_3 - I_4$$

$$4 = 1k\,I + 1k\,I_x$$
$$4 = 1k(I_2 - I_1) + 1k(I_2 - I_3)$$
$$-6 = -1k\,I_x - 1k\,I' + 1k\,I''$$

$$-6 = -1k I_1 - 1k I_2 + 3k I_3 - 1k I_4$$
$$6 = -1k I' + 1k I_4$$
$$6 = -1k I_3 + 2k I_4$$
$$I_5 = I_{sc} = 3.4mA$$

$$R_{TH} = \frac{4.86}{3.4m} = 1.43k\Omega$$



$$V_o = \left(\frac{1k}{1k + 1.43k}\right)(4.86) = 2V$$

5.68 Find the Thévenin equivalent of the circuit in Fig. P5.68 at the terminals *A*-*B*.

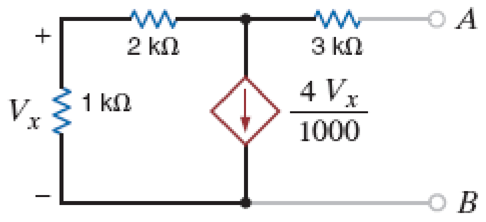
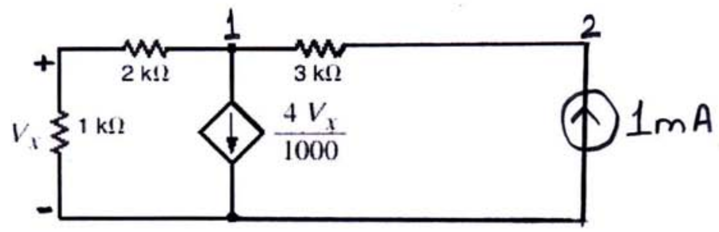


Figure P5.68

SOLUTION:



$$1m = \frac{V_1}{3k} + \frac{4V_x}{1000}$$

$$3 = V_1 + 12V_x$$

$$V_x = \frac{V_1}{3k}(1k) = \frac{V_1}{3}$$

$$3 = V_1 + 12\left(\frac{V_1}{3}\right)$$

$$V_1 = \frac{3}{5}\,V$$

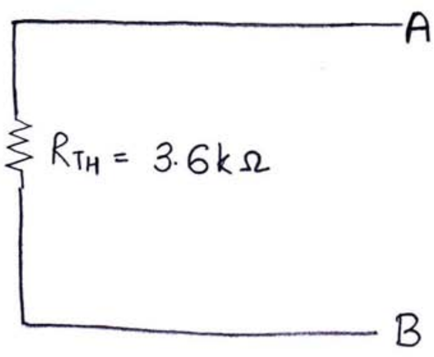
$$V_x = \frac{1}{3}\left(\frac{3}{5}\right) = \frac{1}{5}\,V$$

$$V_2 - V_1 = 3k(1m)$$

$$V_2 = \frac{3}{5} + 3k(1m) = \frac{18}{5} = 3.6\,V$$

$$R_{TH} = \frac{3.6}{1m} = 3.6\,k\Omega$$

Since there are no independent sources,
$V_{OC} = 0V$.



5.69 Find the Thévenin equivalent of the network in Fig. P5.69 at the terminals *A-B* using a 1-mA current source.

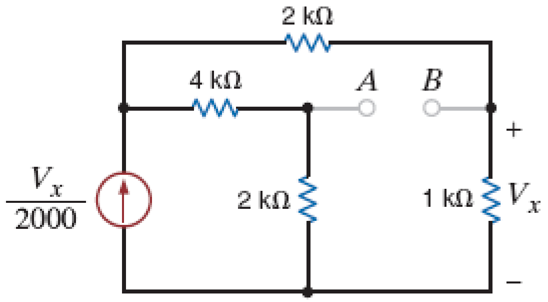
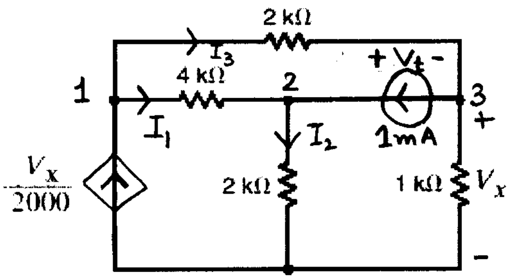


Figure P5.69

SOLUTION:



KCL at 2: $\frac{V_1 - V_2}{4k} + 1m = \frac{V_2}{2k}$

$V_1 - 3V_2 = -4$

KCL at 3: $\frac{V_1 - V_3}{2k} = 1m + \frac{V_3}{1k}$

$V_1 - 3V_3 = 2$

KCL at 1: $\frac{V_x}{2000} = \frac{V_1 - V_2}{4k} + \frac{V_1 - V_3}{2k}$

$V_x = V_3$

$$\frac{V_3}{(2000)} = \frac{V_1 - V_2}{4k} + \frac{V_1 - V_3}{2k}$$

$3V_1 - V_2 - 4V_3 = 0$

$V_1 - 3V_2 = -4$

$$V_2 = \frac{V_1 + 4}{3}$$

$$V_1 - 3\left(\frac{V_1 + 4}{3}\right) - 4V_3 = 0$$

$$V_3 = -1V$$

$$V_1 - 3(-1) = 2$$

$$V_1 = -1V$$

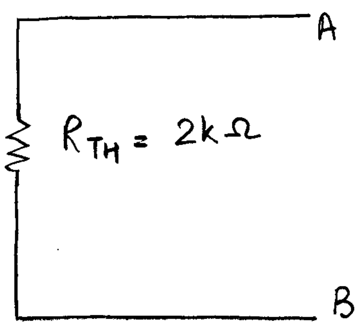
$$V_2 = \frac{-1 + 4}{3} = 1V$$

$$V_t = 1 + 1 = 2V$$

$$R_{TH} = \frac{2}{1m} = 2k\Omega$$

Since there are no independent sources,

$$V_{OC} = 0\,V.$$



5.70 Find the Thévenin equivalent of the network in Fig. P5.70 at the terminals *A-B*.

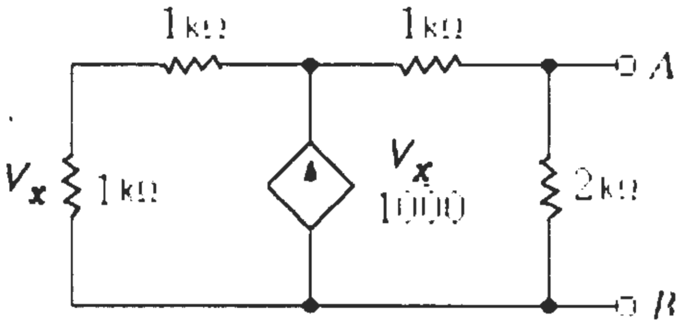
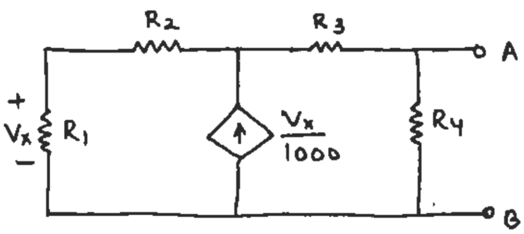


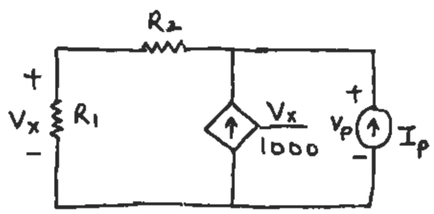
Figure P5.70

Solution: 5.70



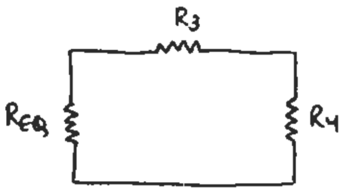
Only dependent source $\Rightarrow$ $V_{oc} = 0\text{ V}$

$R_1 = R_2 = R_3 = 1\,k\Omega$; $R_4 = 2\,k\Omega$



$$I_p + \frac{V_x}{1000} - \frac{V_x}{R_1} = 0$$

$$\Rightarrow I_p = 0$$



$$R_{EQ} = \frac{V_p}{I_p} = \infty$$

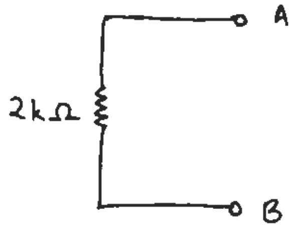
$$R_{Th} = R_4 \parallel (R_3 + R_{EQ})$$

$$= \frac{R_4\,(R_3 + R_{EQ})}{R_4 + R_3 + R_{EQ}}$$

$$\sim R_4$$

$$R_{Th} = 2\,k\Omega$$

Thevenin Eq



$(\because V_{oc} = 0\,V)$

5.71 Find the Thévenin equivalent of the network in Fig. P5.71 at the terminals *A*-*B*.

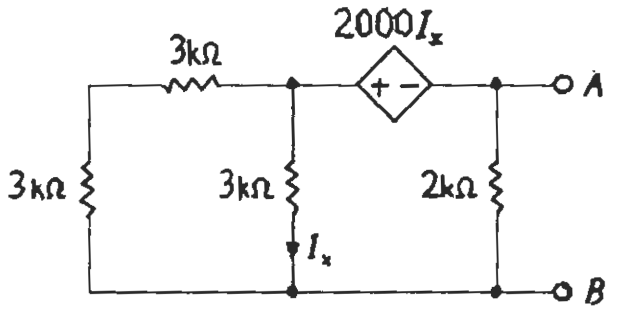
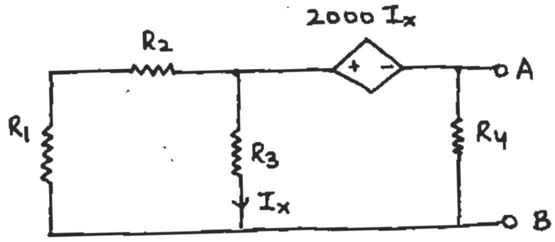


Figure P5.71

Solution: 5.71

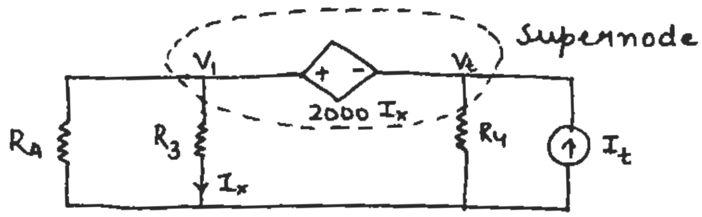


$R_1 = R_2 = R_3 = 3k\Omega$,

$R_4 = 2k\Omega$

$V_{oc} = 0V$

$R_A = R_1 + R_2 = 6k\Omega$



$V_1 - V_t = 2000\ I_x$ ——— (1)

$I_x = \frac{V_1}{R_3}$ ——— (2)

From (1) and (2), we get

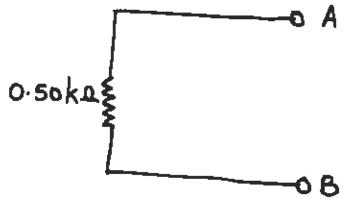
$V_1 = 3V_t$

KCL @ supernode : $\frac{V_1}{R_A} + \frac{V_1}{R_3} + \frac{V_t}{R_4} - I_t = 0$

$\frac{V_t}{I_t} = 0.50\ k\Omega$

$R_{Th} = \frac{V_t}{I_t} \Rightarrow R_{Th} = 0.50\ k\Omega$

Thevenin Eq



5.72 Find the Thévenin equivalent of the network below at the terminals A-B in Fig. P5.72.

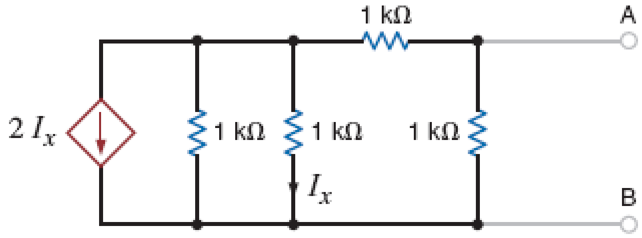
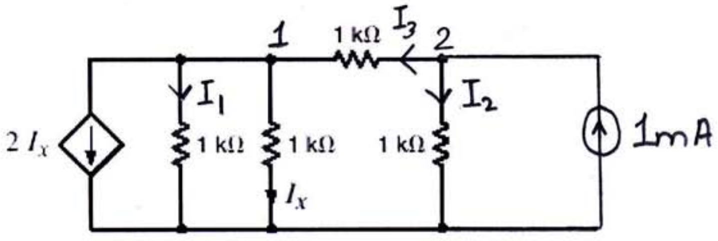


Figure P5.72

SOLUTION:



KCL at 2: $1m = \dfrac{V_2}{1k} + \dfrac{V_2 - V_1}{1k}$

$-V_1 + 2V_2 = 1$

KCL at 1: $\dfrac{V_2 - V_1}{1k} = \dfrac{V_1}{1k} + \dfrac{V_1}{1k} + 2I_x$

$I_x = \dfrac{V_1}{1k}$

$\dfrac{V_2 - V_1}{1k} = \dfrac{V_1}{1k} + \dfrac{V_1}{1k} + 2\left(\dfrac{V_1}{1k}\right)$

$5V_1 - V_2 = 0$

$V_1 = 0.111V$

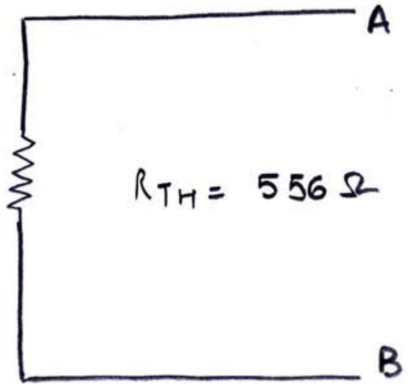
$V_2 = 0.556V$

$R_{TH} = \dfrac{0.556}{1m}$

$= 556\Omega$

Since there are no independent sources,

$V_{oc} = 0V.$



5.73 Find the Thévenin equivalent circuit of the network in Fig. P5.73 at terminals *A*-*B*.

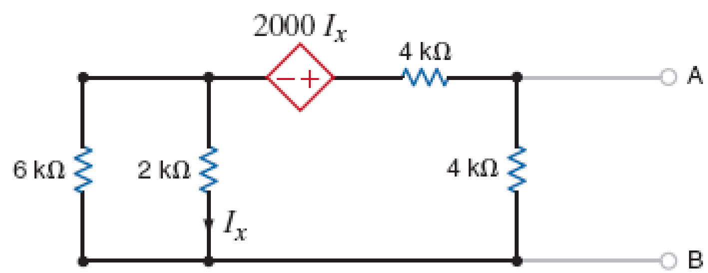
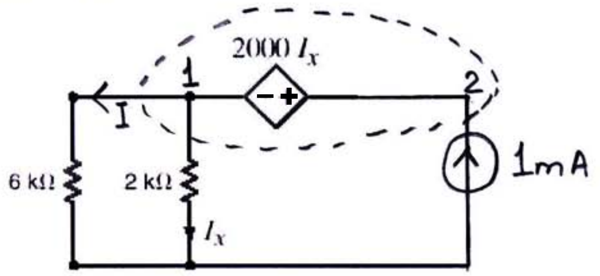


Figure P5.73

SOLUTION:



KCL at the supernode:

$$1m = \frac{V_1}{6k} + \frac{V_1}{2k}$$

$$V_1 = \frac{3}{2}\ V$$

$$I_x = \frac{V_1}{2k}$$

$$V_2 - V_1 = 2000\, I_x$$

$$V_2 - V_1 = 2000\left(\frac{V_1}{2k}\right)$$

$$V_2 = 2V_1$$

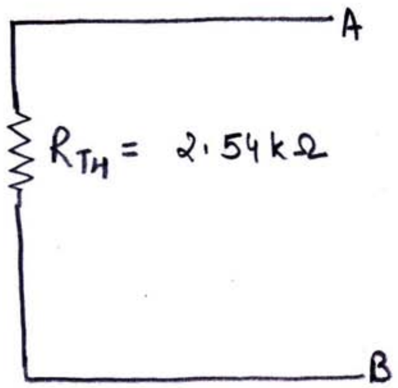
$$V_2 = 2\left(\frac{3}{2}\right)$$

$$V_2 = 3V$$

$$R = \frac{3}{1m} = 3k\Omega$$

$$R_{TH} = 4k \,||\, (4k + R) = 4k \,||\, 7k$$
$$= 2.54\,k\Omega$$

Since there are no independent sources,
$V_{OC} = 0\ V.$



5.74 Find I_o in the network in Fig. P5.74 using source transformation.

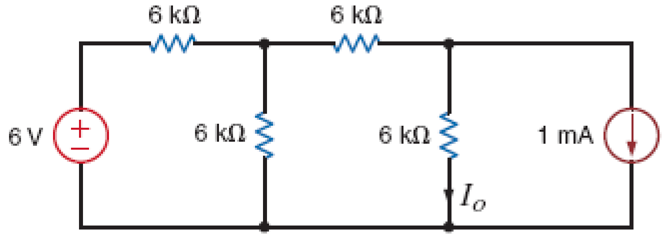
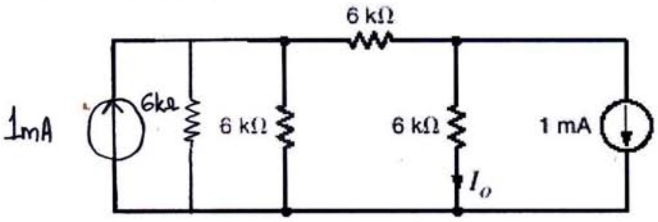
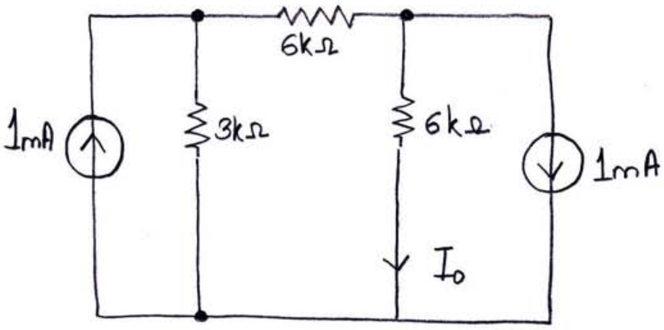
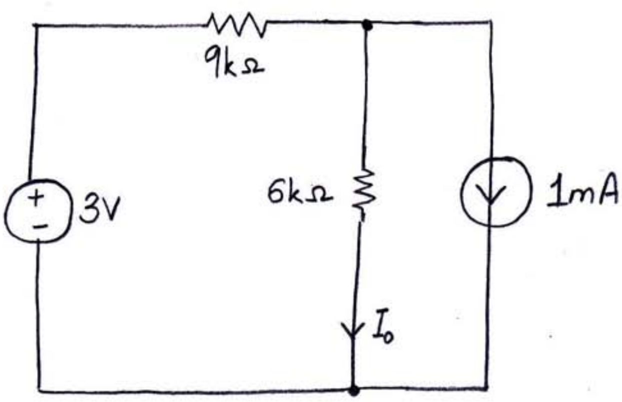


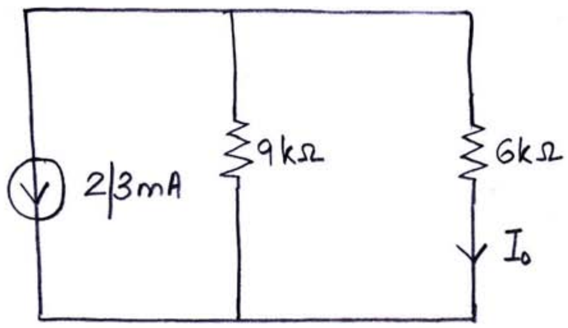
Figure P5.74

SOLUTION:









$$I_0 = \left(\frac{9k}{9k+6k}\right)\left(-\frac{2}{3}m\right) = -0.4mA$$

5.75 Use source transformation to find V_o in the network in Fig. P5.75.

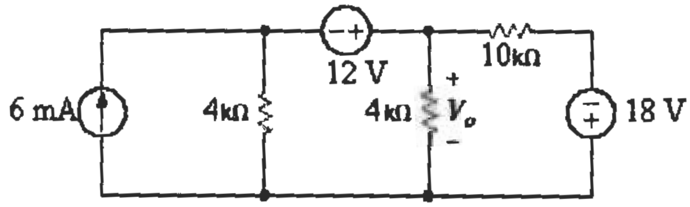
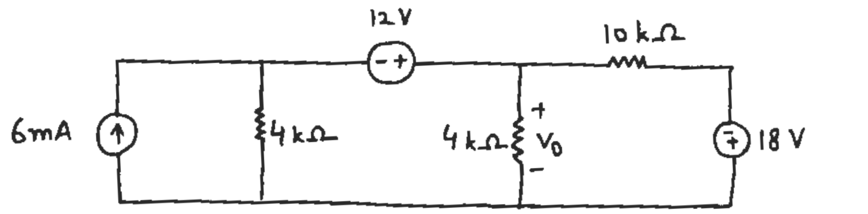
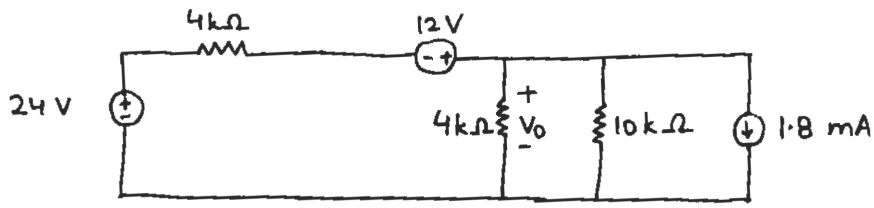
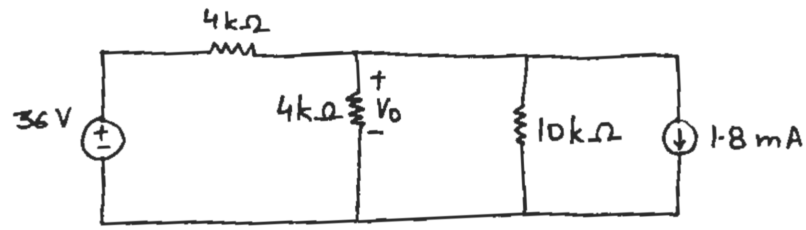


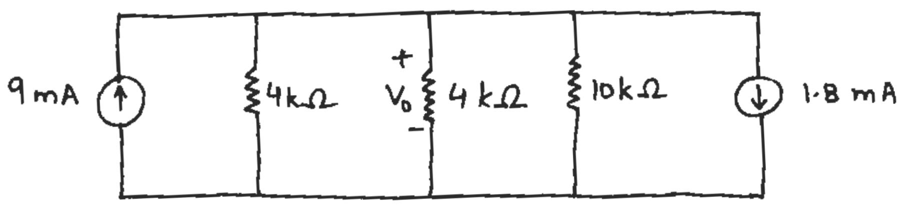
Figure P5.75

Solution: 5.75

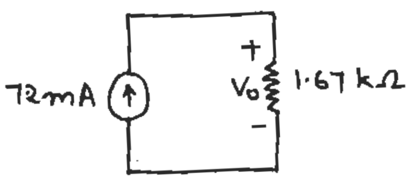








$R_{eq} = 4 \| 4 \| 10 = 1.67\ k\Omega$



$\boxed{V_0 = 12.0\ V}$

5.76 Find I_o in the network in Fig. P5.76 using source transformation.

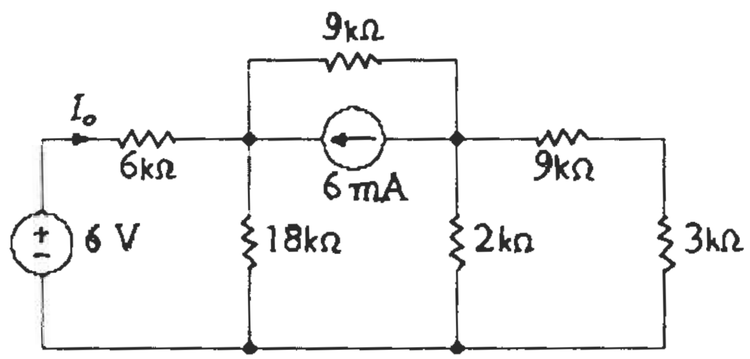
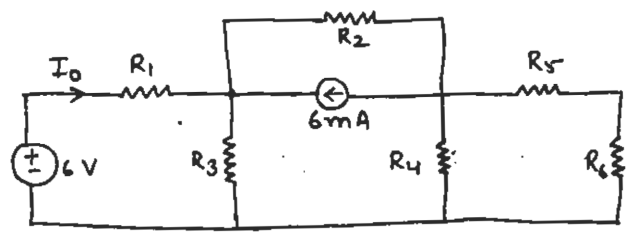


Figure P5.76

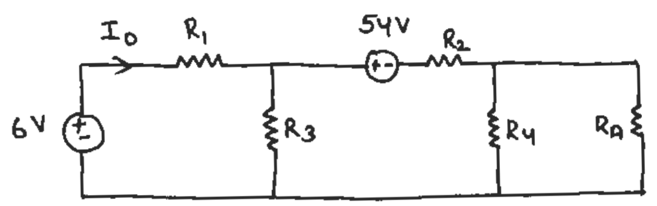
Solution: 5.76



$R_1 = 6\,k\Omega,\ R_2 = 9\,k\Omega,$

$R_3 = 18\,k\Omega,\ R_4 = 2\,k\Omega,$

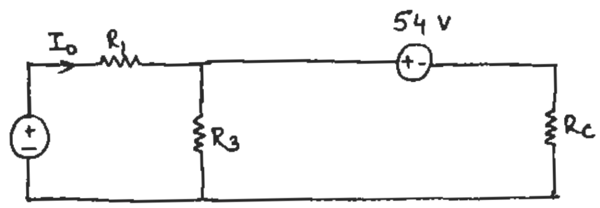
$R_5 = 9\,k\Omega,\ R_6 = 3\,k\Omega$

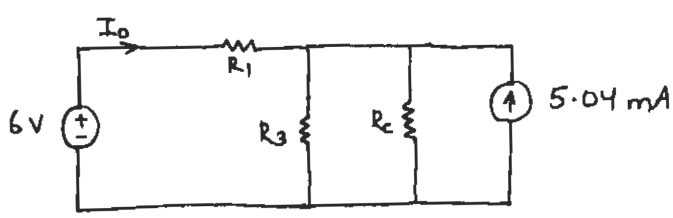


$R_A = R_5 + R_6 = 12\,k\Omega$

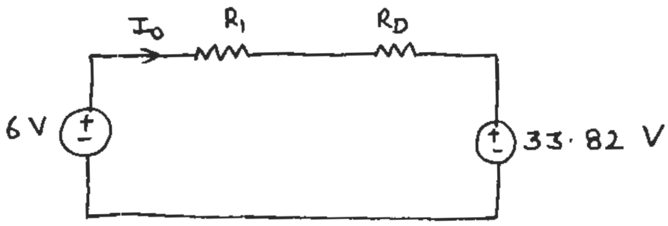
$R_B = R_4 \| R_A = \frac{12}{7}\,k\Omega$

$R_C = R_2 + R_B = \frac{75}{7}\,k\Omega$





$R_D = R_C \| R_3 = 6.71\,k\Omega$



$$6 = I_o(R_1 + R_D) + 33.82$$

$$\boxed{I_o = -2.19 \text{ mA}}$$

5.77 Find V_o in the network in Fig. P5.77 using source transformation.

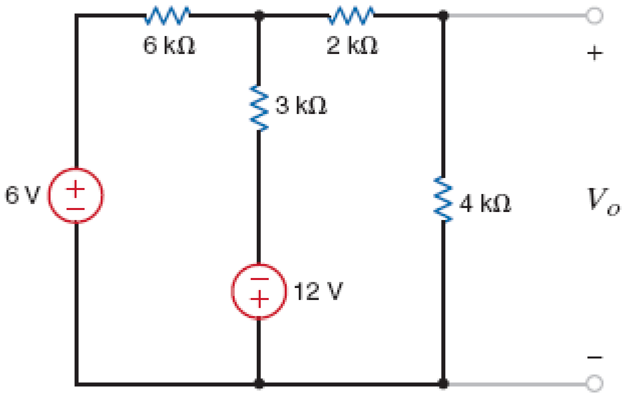
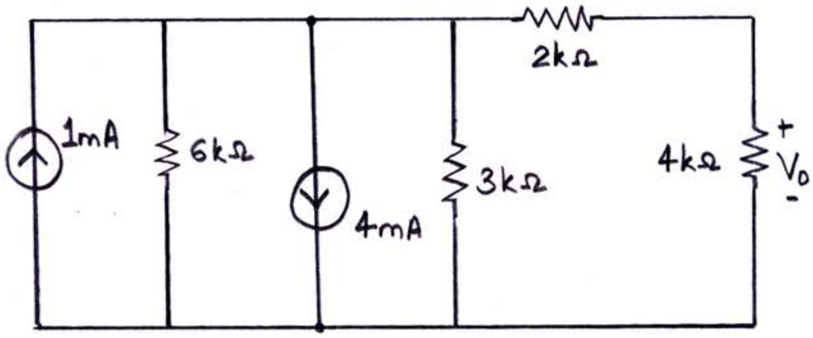
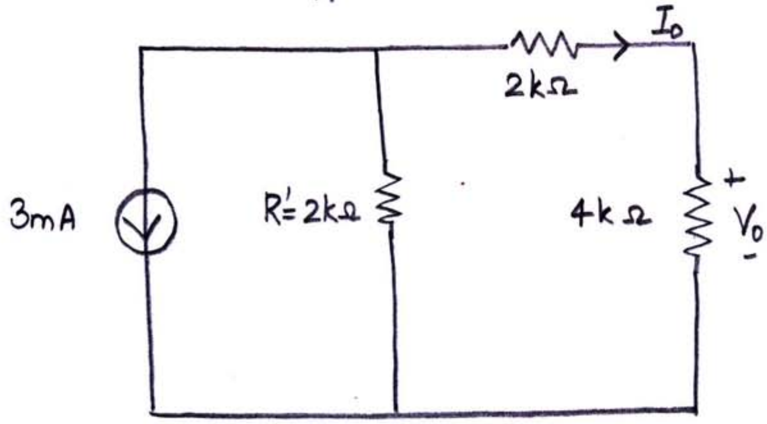


Figure P5.77

SOLUTION:



$R' = 6k \| 3k = 2k\Omega$



$$I_0 = \left(\frac{-2k}{2k+2k+4k}\right)(3m)$$

$$= -0.75mA$$

$$V_0 = 4k(-0.75m)$$

$$= -3V$$

5.78 Use source transformation to find I_o in the network in Fig. P5.78.

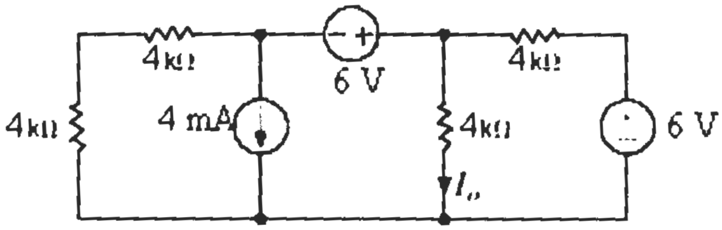
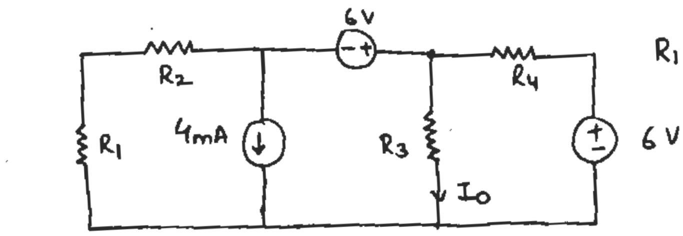
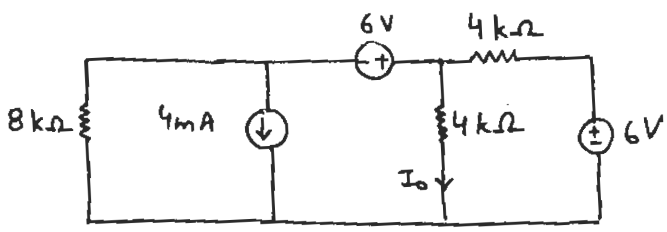


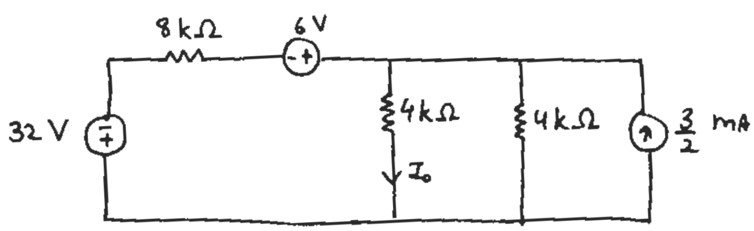
Figure P5.78

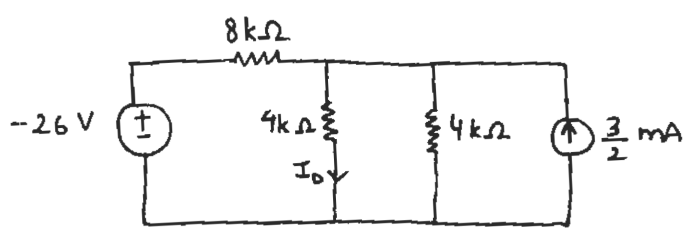
Solution: 5.78

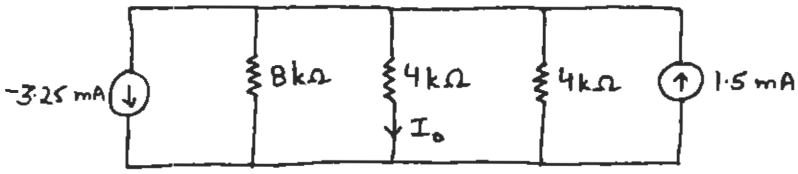


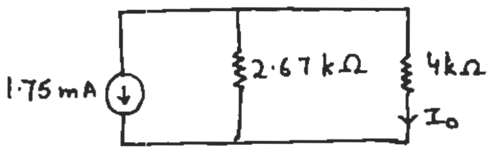
$R_1 = R_2 = R_3 = R_4 = 4\,k\Omega$











By Current Division

$$I_o = -1.75 \times 10^{-3}\left[\frac{2.67}{6.67}\right]$$

$$\boxed{I_o = -0.700 \text{ mA}}$$

5.79 Find V_o in the network in Fig. P5.79 using source transformation.

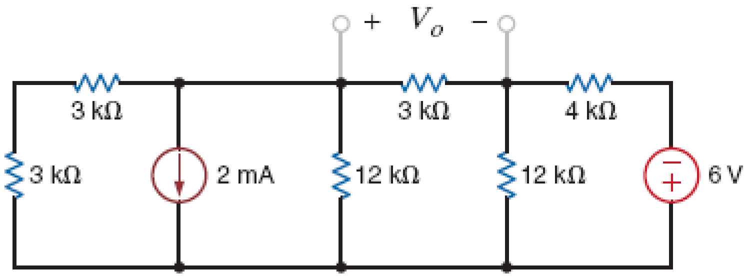
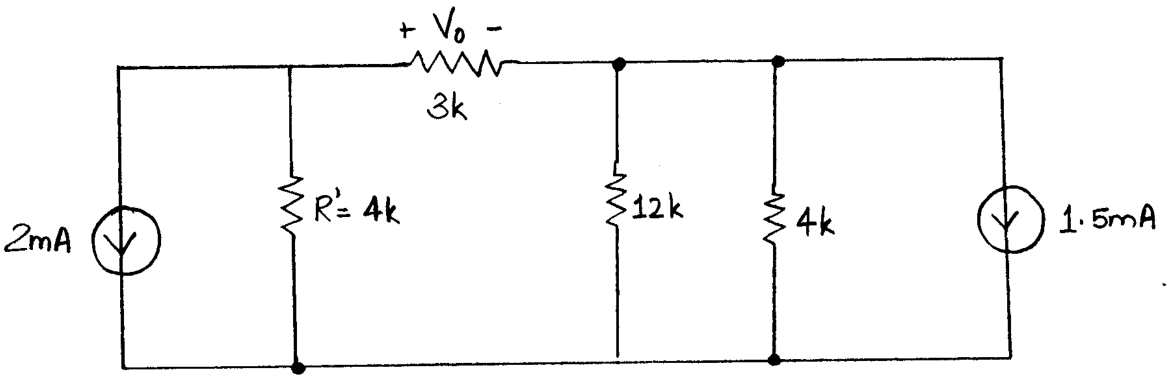


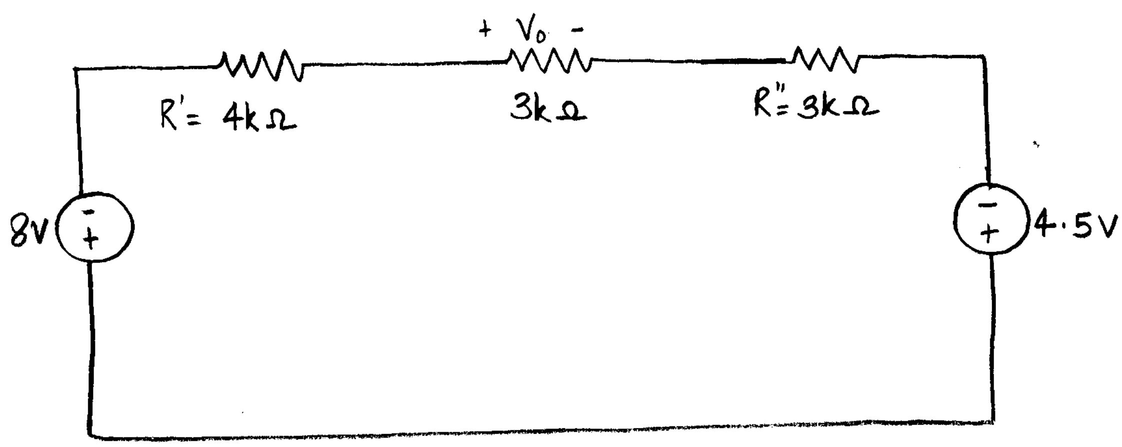
Figure P5.79

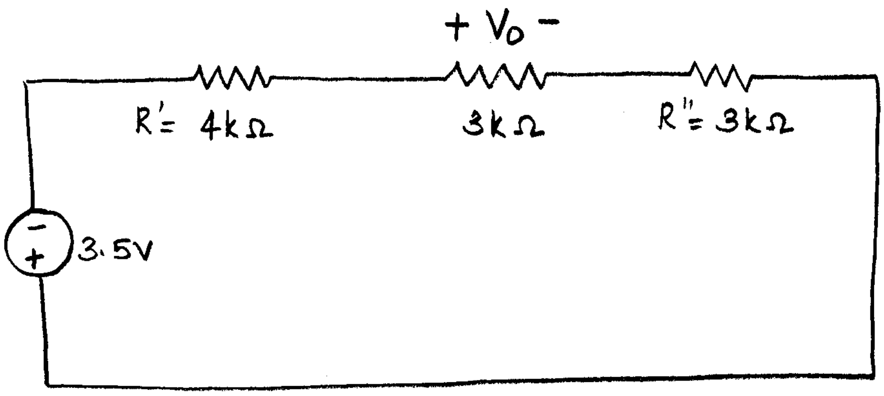
SOLUTION:



$R' = 6k \,||\, 12k = 4k\Omega$

$R'' = 12k \,||\, 4k = 3k\Omega$





$$V_0 = \left(\frac{3k}{3k+3k+4k}\right)(-3.5)$$

$$= -1.05V$$

5.80 Find V_o in the network in Fig. P5.80 using source transformation.

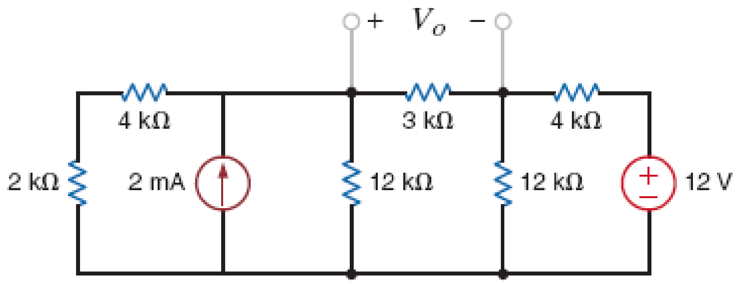
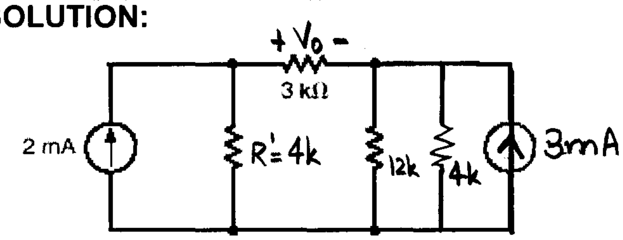


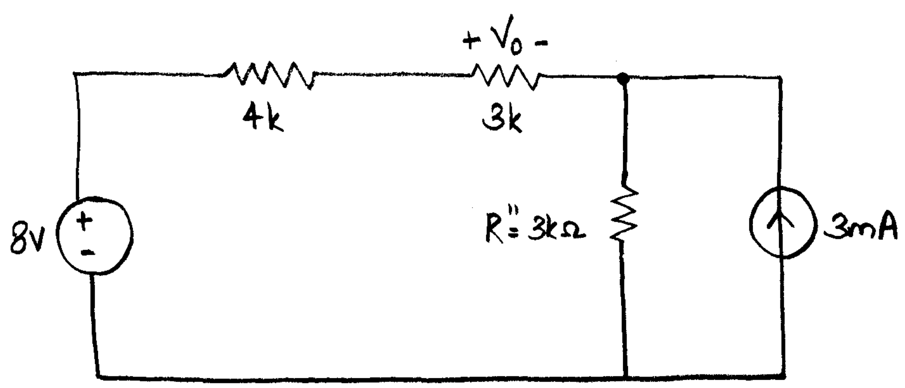
Figure P5.80

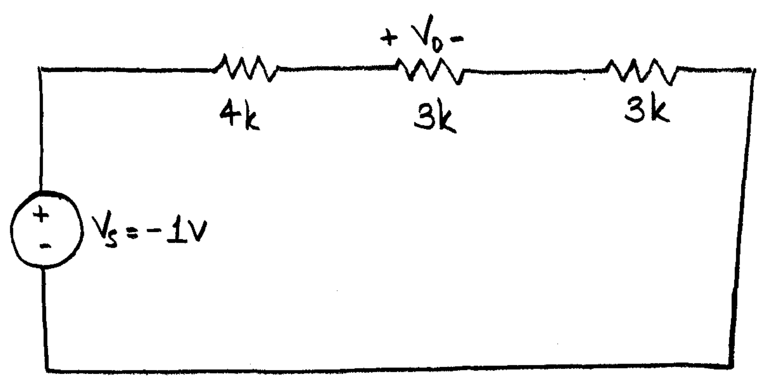
SOLUTION:



$R' = 6k \,||\, 12k = 4k\Omega$

$R'' = 12k \,||\, 4k = 3k\Omega$





$$V_0 = \left(\frac{3k}{3k+3k+4k}\right)(-1) = -0.3V$$

5.81 Find I_o in the network in Fig. P5.81 using source transformation.

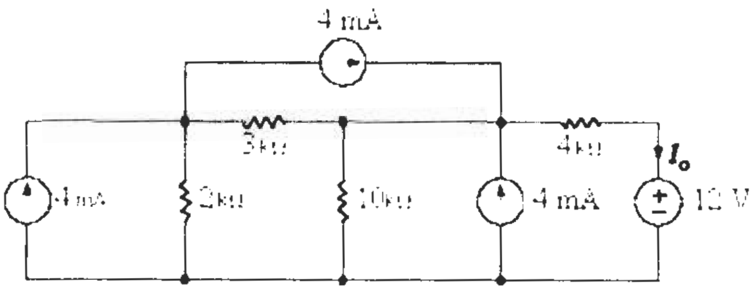
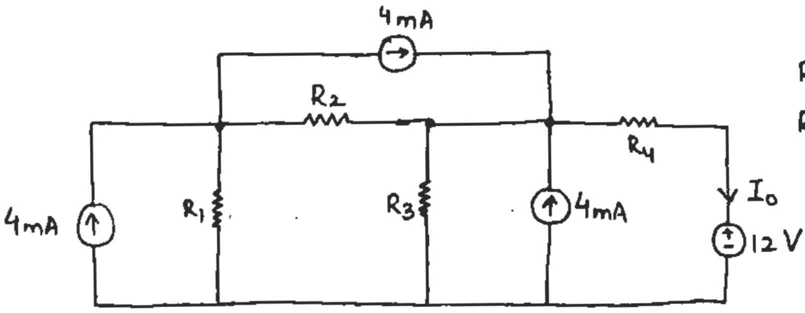
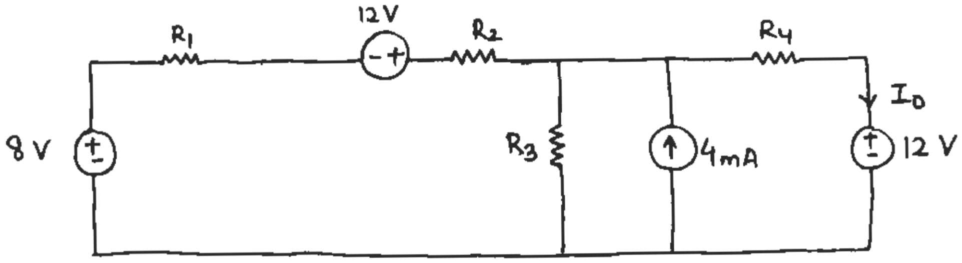


Figure P5.81

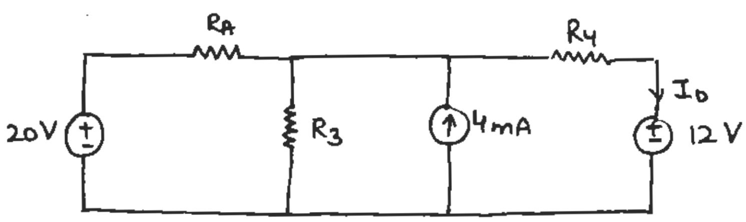
Solution: 5.81

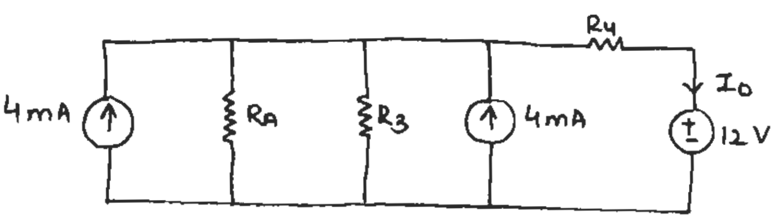


$R_1 = 2k\Omega, R_2 = 3k\Omega,$
$R_3 = 10k\Omega, \ R_4 = 4k\Omega$

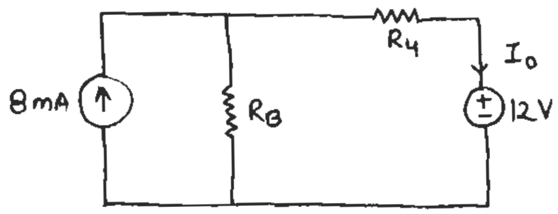


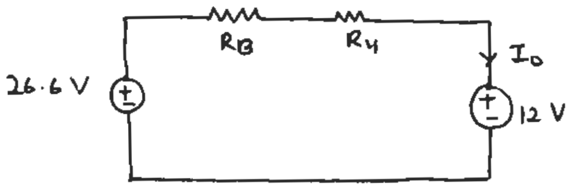
$$R_A = R_1 + R_2 = 5\ k\Omega$$





$$R_B = R_A \parallel R_3 = 3.33\ k\Omega$$





$$I_o = \frac{26.6 - 12}{R_B + R_4}$$

$$I_o = 1.99 \text{ mA}$$

$$\boxed{I_o = 2.00 \text{ mA}}$$

5.82 Find I_o in the circuit in Fig. P5.82 using source transformation.

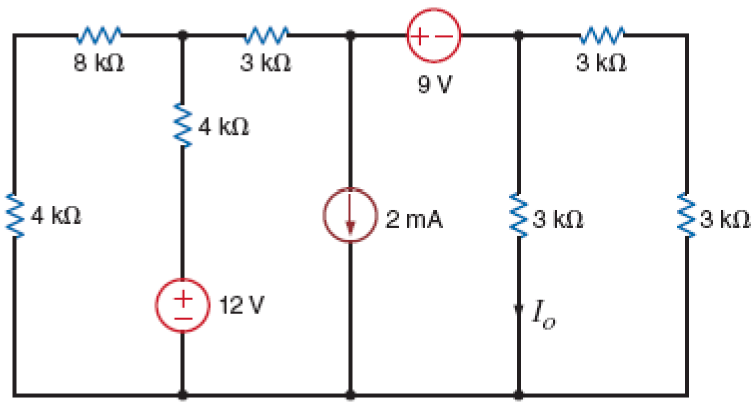
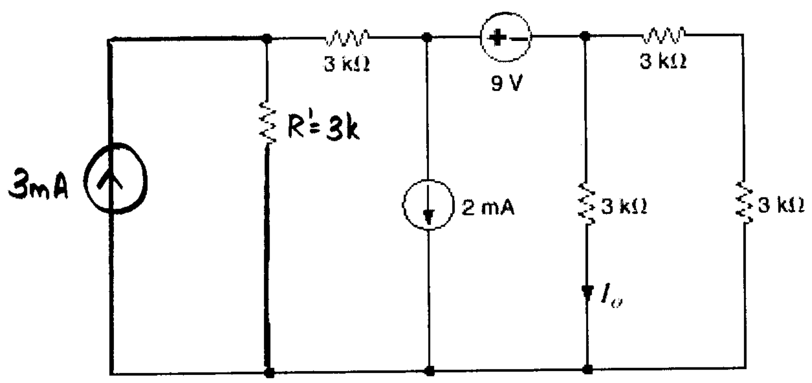


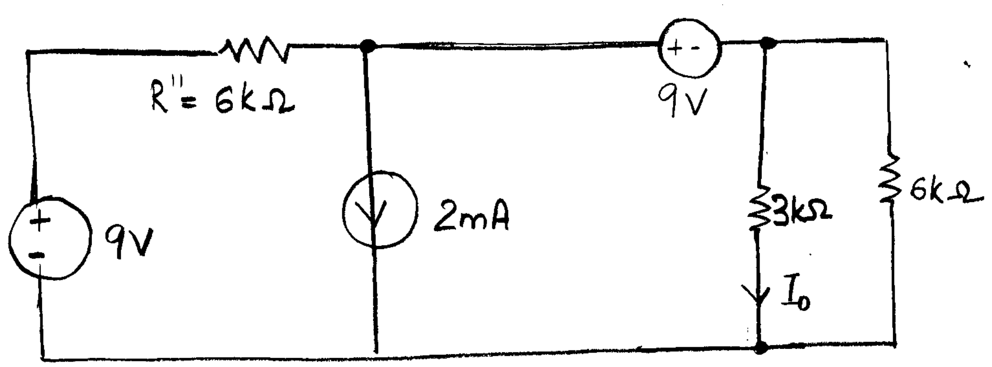
Figure P5.82

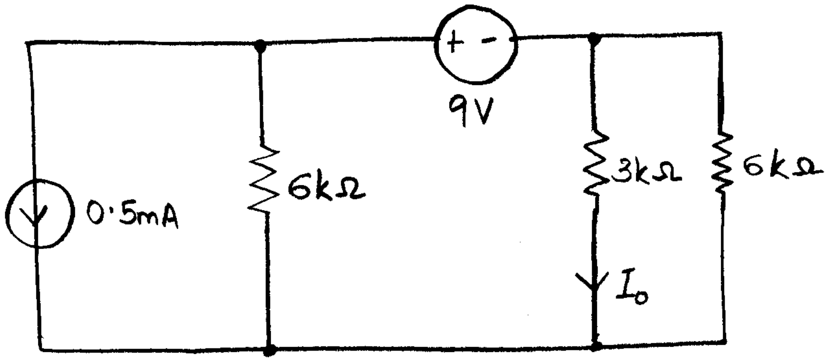
SOLUTION:

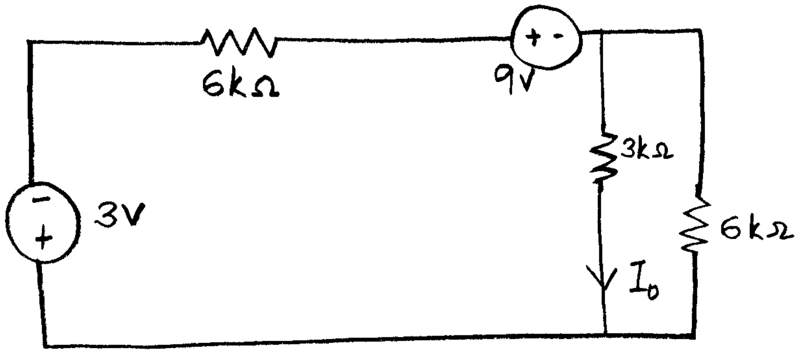
$$R' = (4k + 8k) \,||\, 4k = 3k\Omega$$

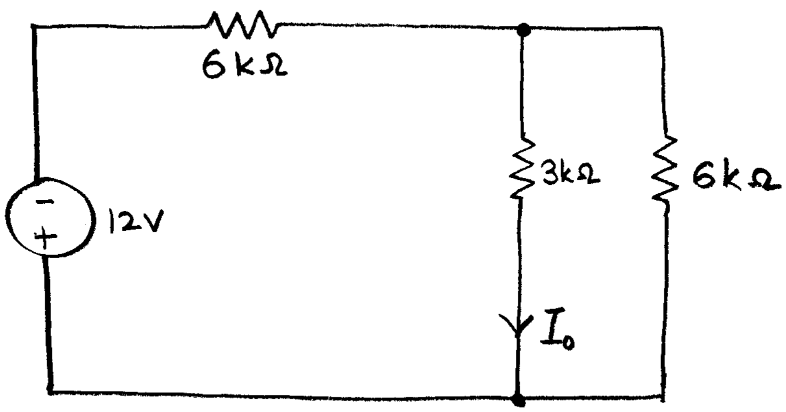


$$R'' = 3k + 3k = 6k\Omega$$

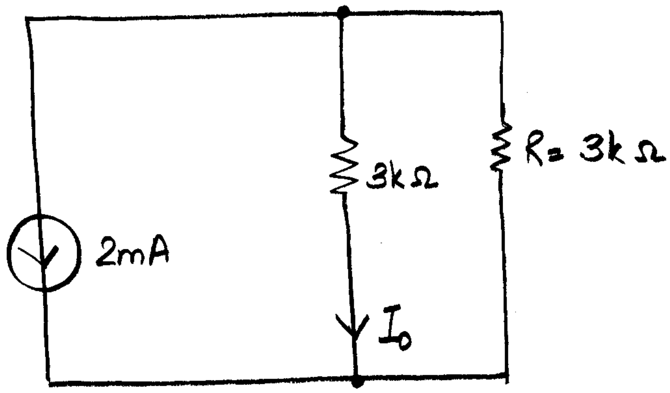








$R = 6k // 6k = 3k\Omega$



$$I_o = \left(\frac{3k}{3k+3k}\right)(-2m)$$

$$= -1mA$$

5.83 Find I_o in the circuit in Fig. P5.83 using source transformation.

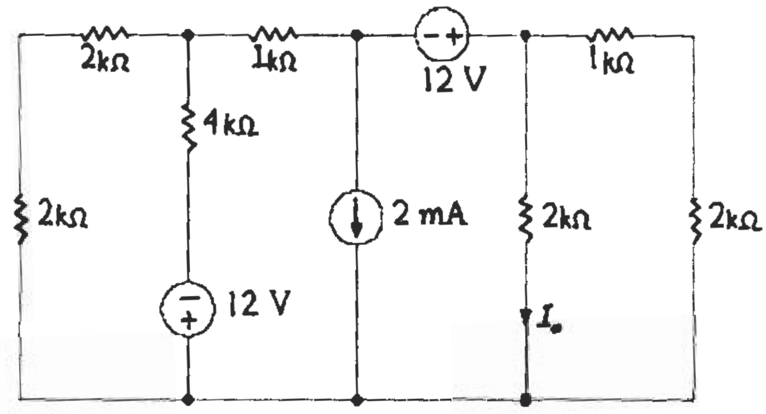
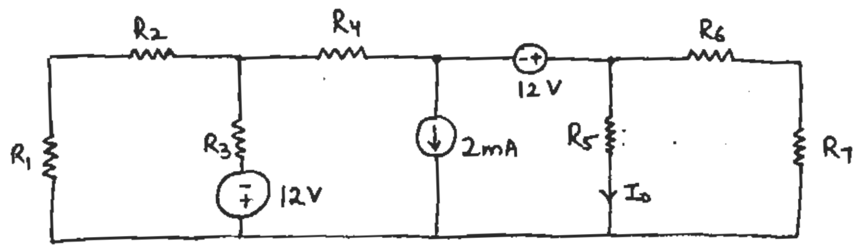


Figure P5.83

Solution: 5.83



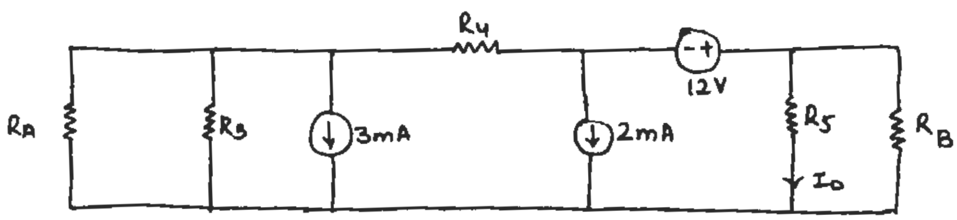
$R_1 = R_2 = 2k\Omega,$

$R_3 = 4k\Omega,$

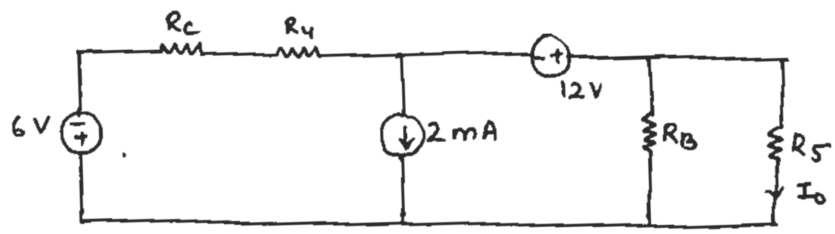
$R_4 = 1k\Omega, R_6 = 1k\Omega$

$R_5 = R_7 = 2k\Omega$

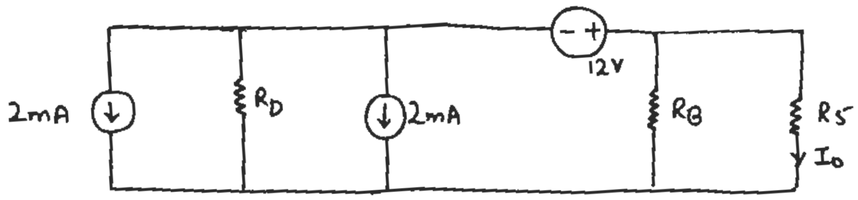
$$R_A = R_1 + R_2 = 4k\Omega \; ; \; R_B = R_6 + R_7 = 3k\Omega$$

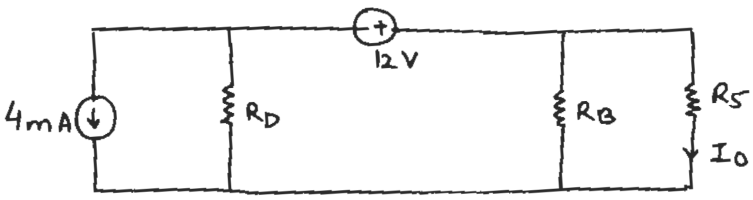


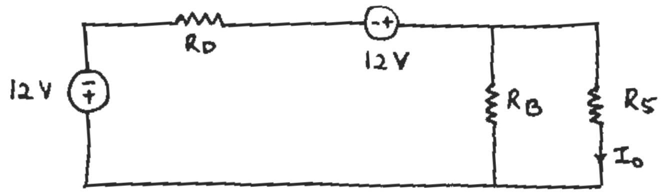
$$R_C = R_A \parallel R_3 = 2k\Omega$$

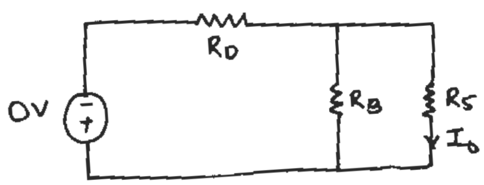


$$R_D = R_C + R_4 = 3k\Omega$$









Here, Voltage = 0

$\Rightarrow \boxed{I_o = 0A}$

5.84 Find I_o in the network in Fig. P5.84 using source transformation.

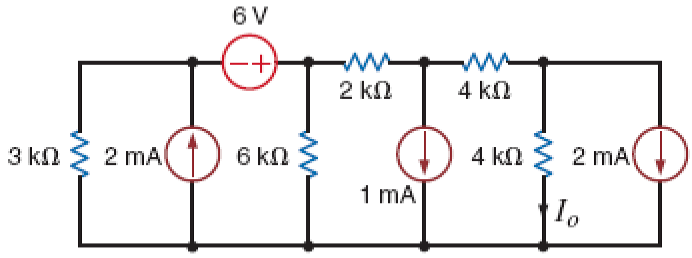
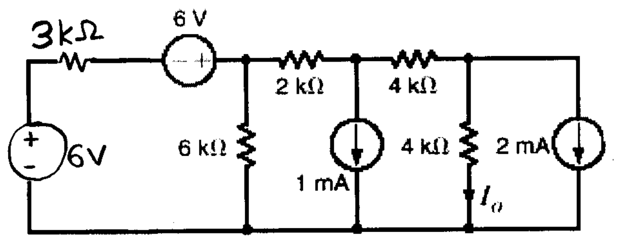
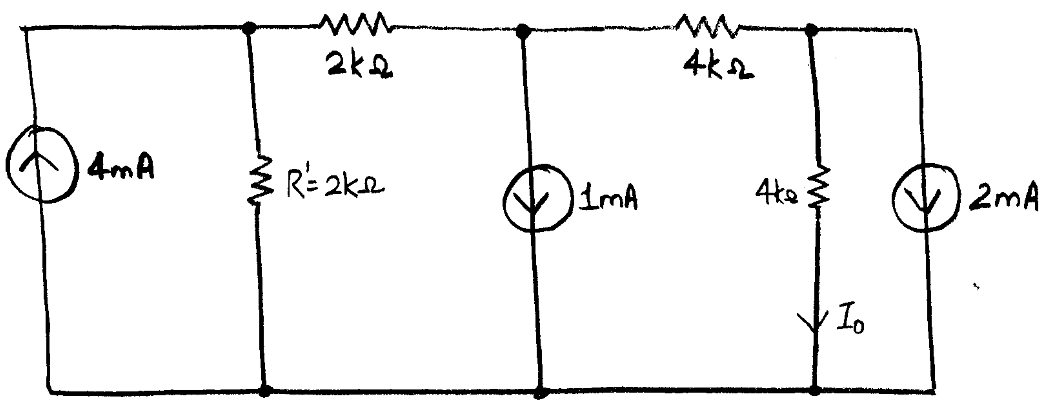


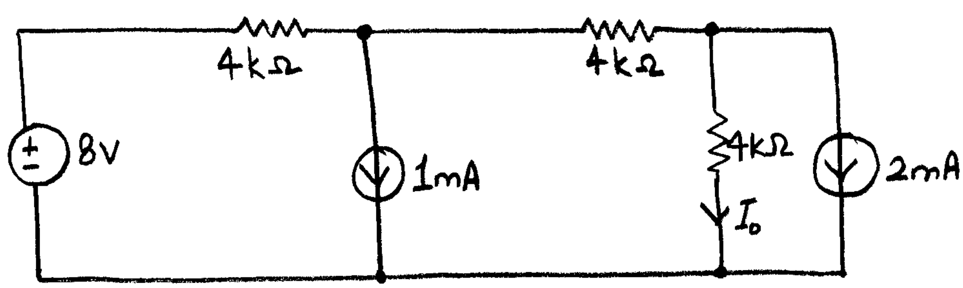
Figure P5.84

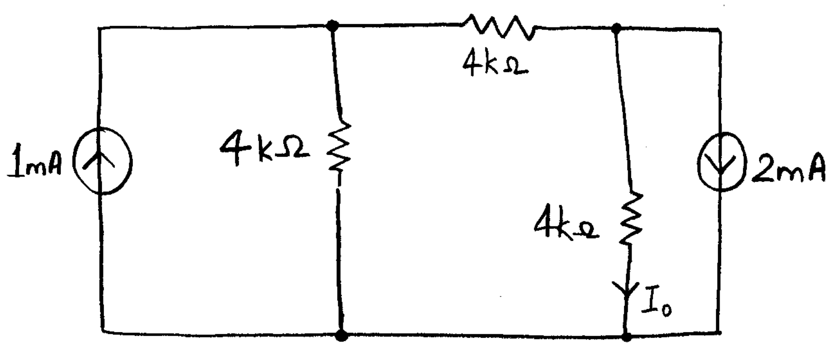
SOLUTION:



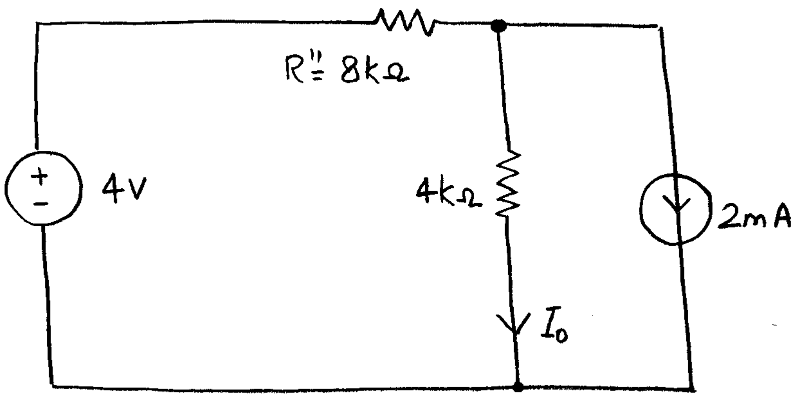
$$R' = 3k \,||\, 6k = 2k\Omega$$

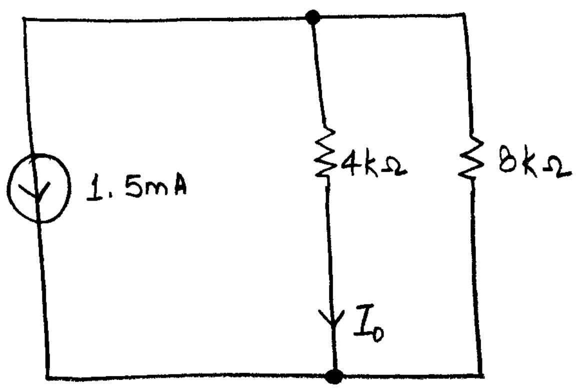






$$R'' = 4k + 4k = 8k\Omega$$





$$I_0 = \left(\frac{8k}{8k+4k}\right)(-1.5m)$$

$$= -1mA$$

5.85 Find I_o in the network in Fig. P5.85 using source transformation.

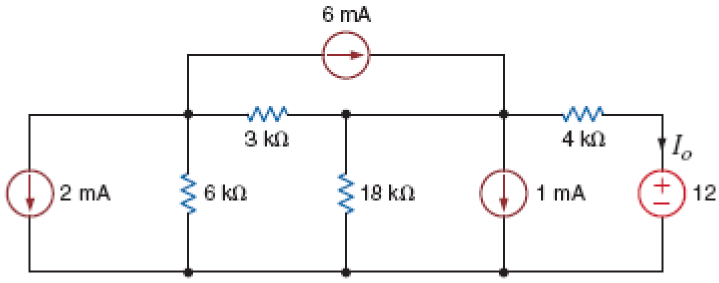
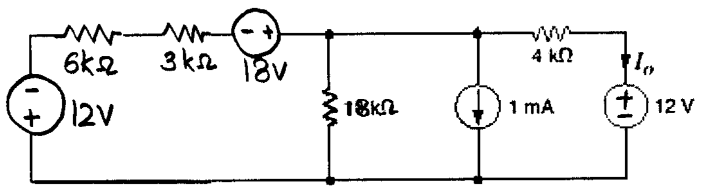
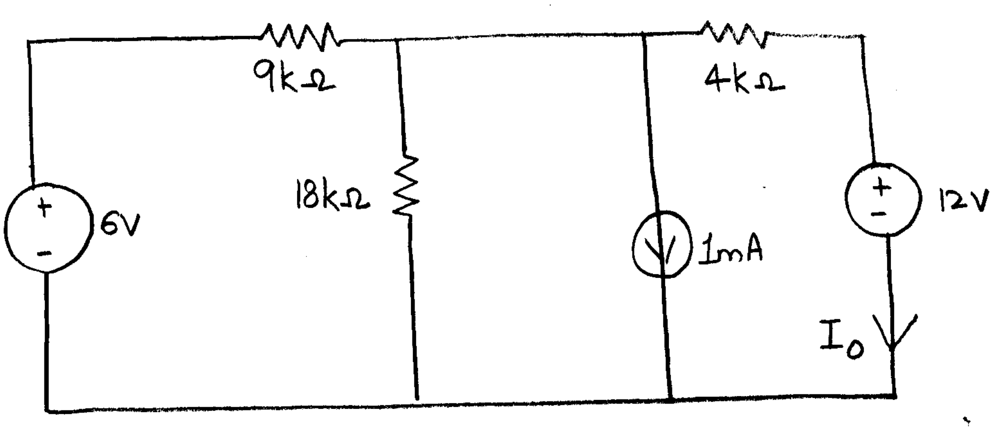


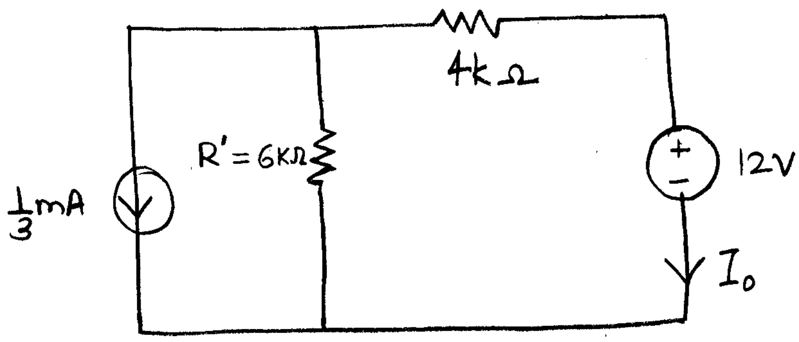
Figure P5.85

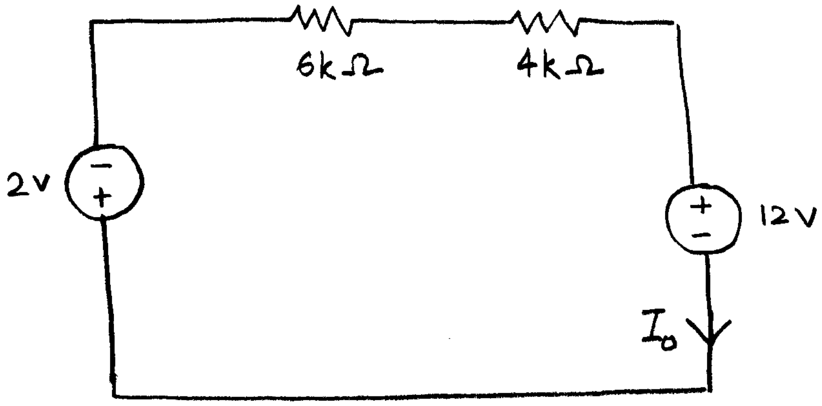
SOLUTION:

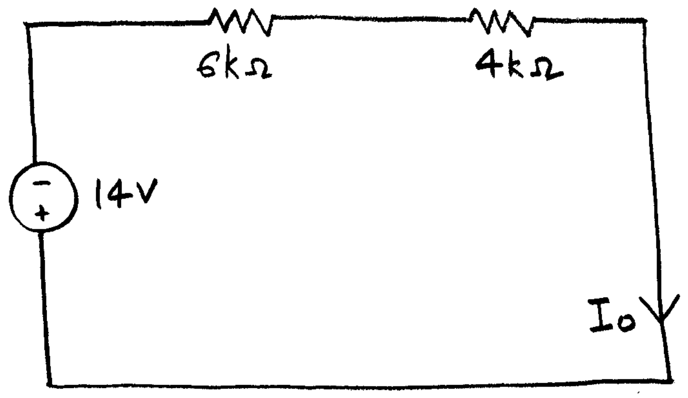




$$R' = 9k \| 18k = 6k\Omega$$







$$I_0 = \frac{-14}{10k}$$

$$= -1.4mA$$

5.86 Use source transformation to find I_o in the network in Fig. P5.86.

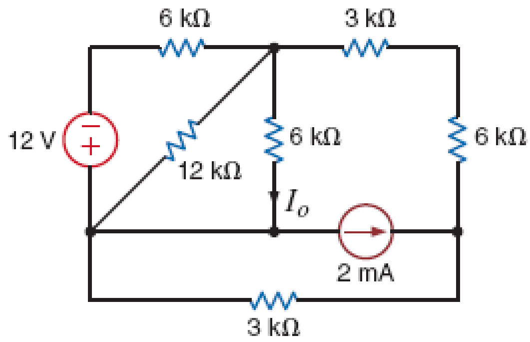
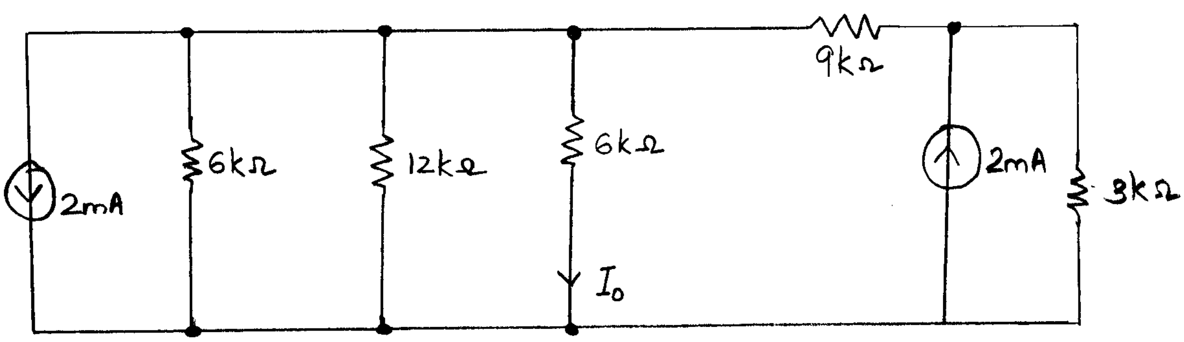
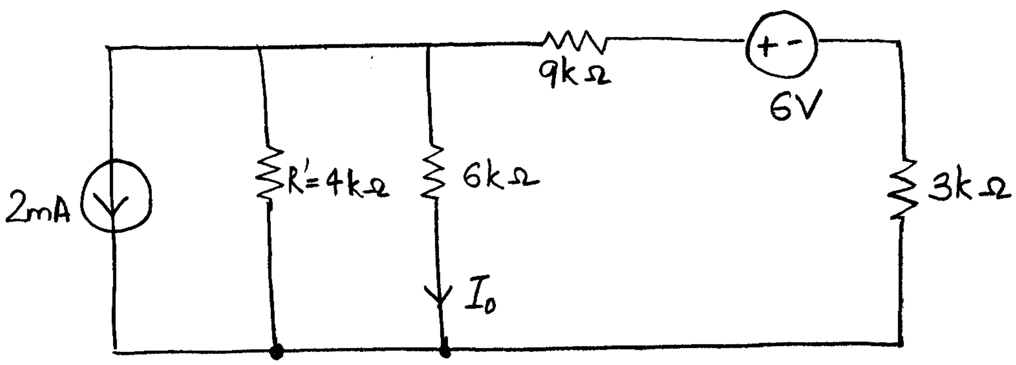


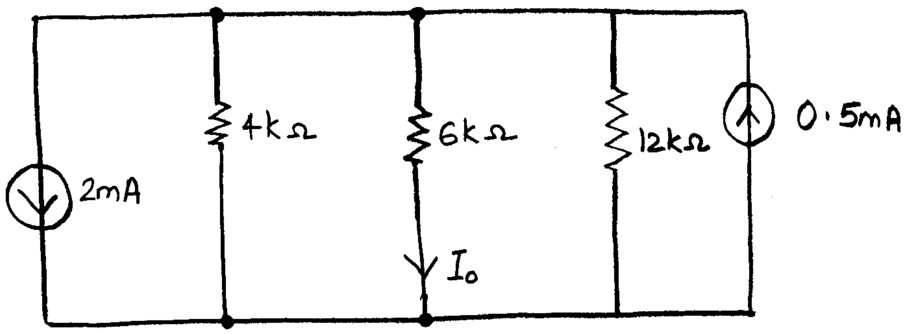
Figure P5.86

SOLUTION:

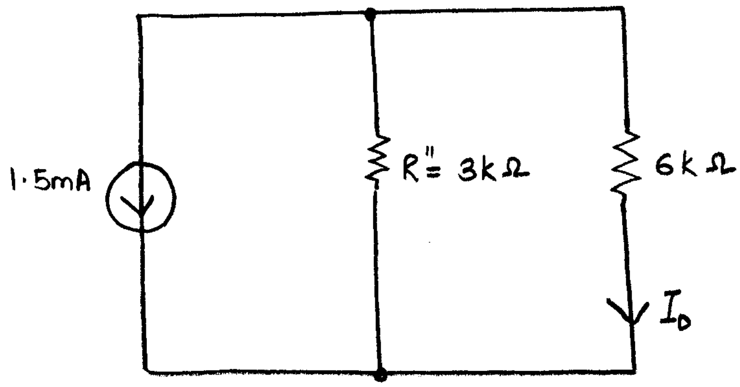


$$R' = 6k // 12k = 4k\Omega$$





$$R'' = 4k \| 12k = 3k\Omega$$



$$I_o = \left(\frac{3k}{3k+6k}\right)(-1.5m)$$

$$= -0.5mA$$

5.87 Use source transformation to find V_o in the network in Fig. P5.87.

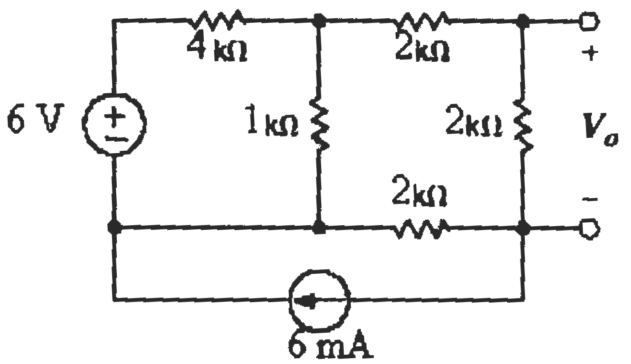
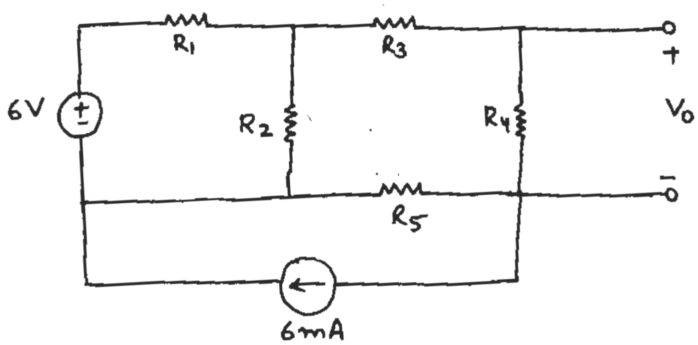


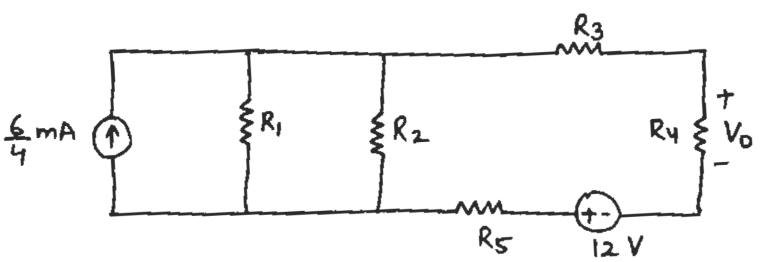
Figure P5.87

Solution: 5.87

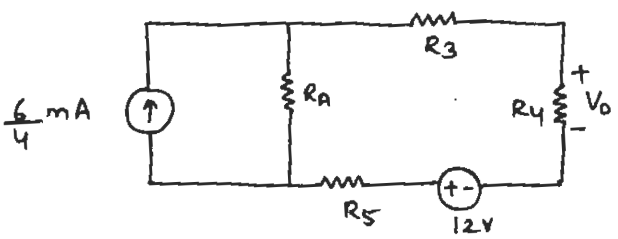
$R_1 = 4\,k\Omega$, $R_2 = 1\,k\Omega$,

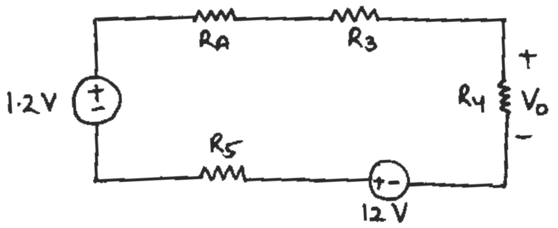
$R_3 = R_4 = R_5 = 2\,k\Omega$





$$R_A = R_1 \| R_2 = \frac{4}{5}\,k\Omega = 0.8\,k\Omega$$





$$V_o = 13.2 \times \frac{R_4}{R_A + R_3 + R_4 + R_5}$$

$$\boxed{V_o = 3.88\ V}$$

5.88 Using source transformation, find I_o in the circuit in Fig. P5.88.

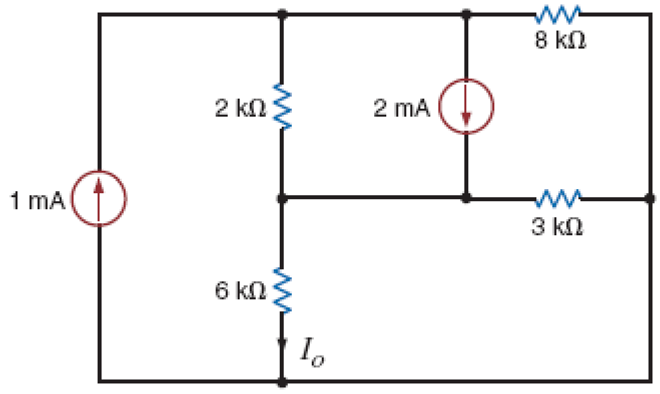
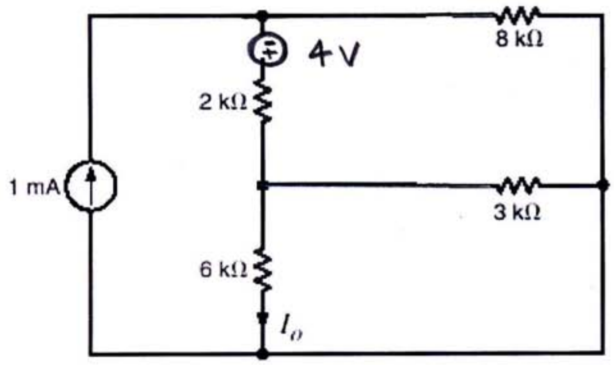
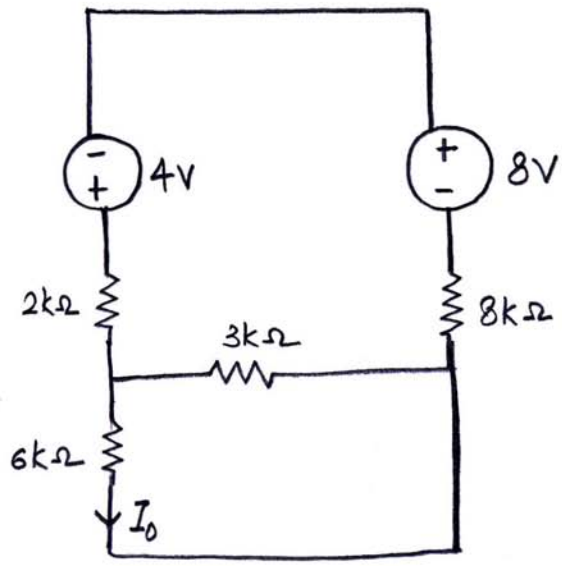
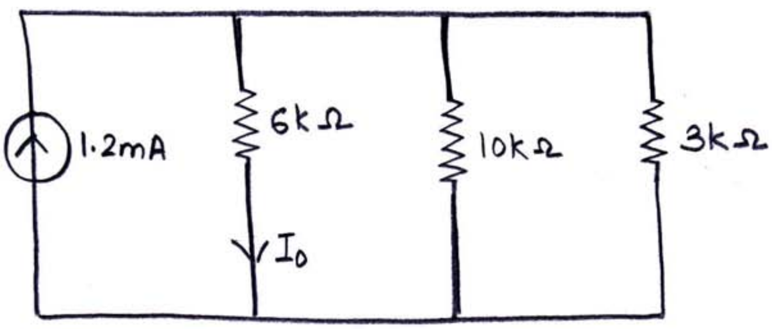


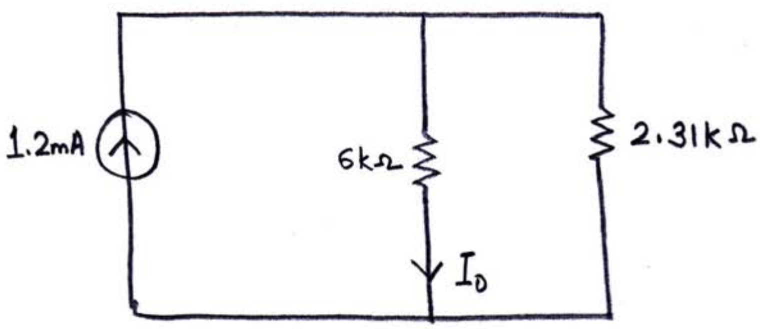
Figure P5.88

SOLUTION:









$$I_o = \left(\frac{2.31k}{2.31k+6k}\right)(1.2m)$$

$$= 0.333mA$$

5.89 Find I_o in the network in Fig. P5.89 using source transformation.

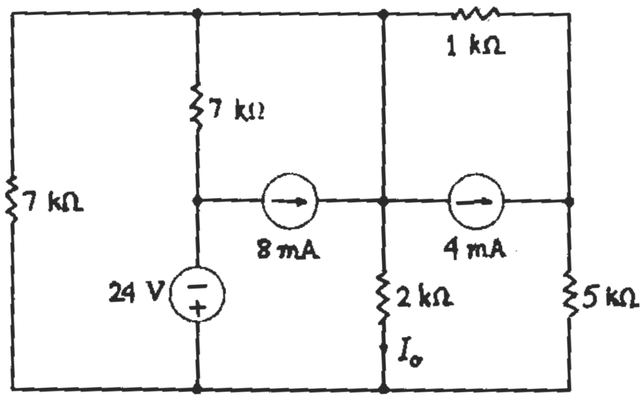
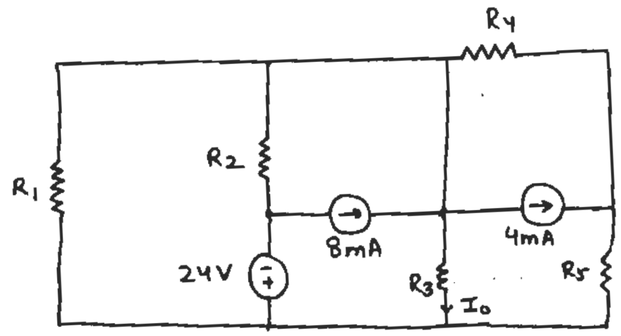


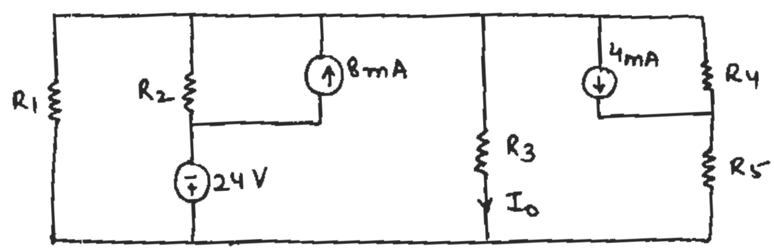
Figure P5.89

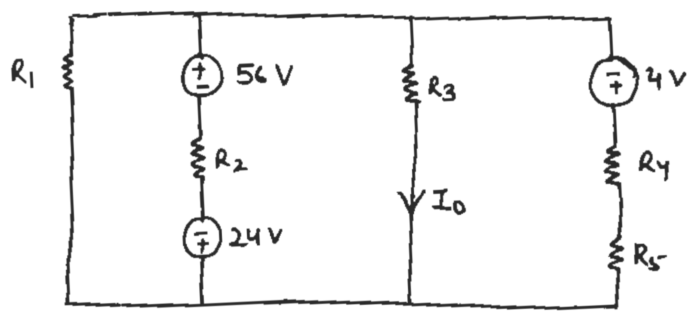
Solution: 5.89



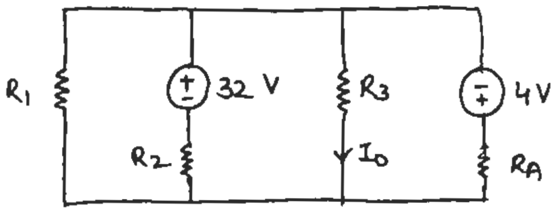
$R_1 = R_2 = 7k\Omega,$
$R_3 = 2k\Omega,\ R_4 = 1k\Omega,$
$R_5 = 5k\Omega$

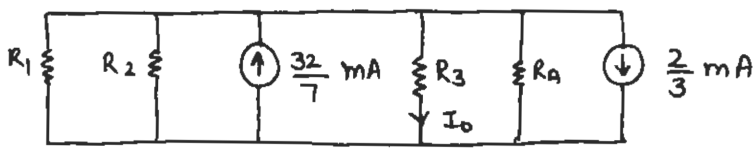
Rearrange Circuit



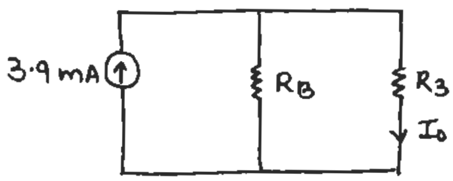


$R_A = R_4 + R_5 = 6k\Omega$





$$R_B = R_1 \,||\, R_2 \,||\, R_A = 2.21\ k\Omega$$



$$I_o = 3.9 \times 10^{-3} \frac{R_B}{R_B + R_3}$$

$$\boxed{I_o = 2.05\ mA}$$

5.90 Using source transformation, find I_o in the network in Fig. P5.90.

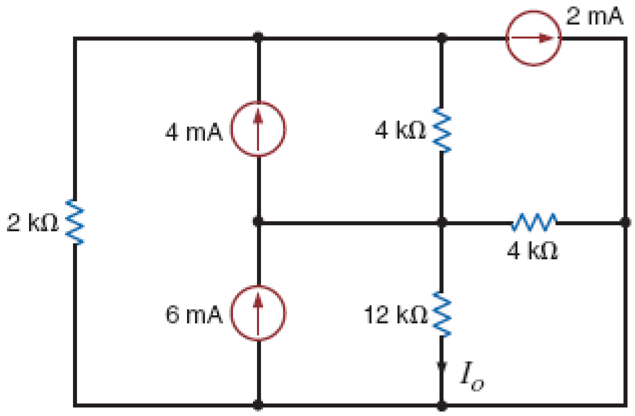
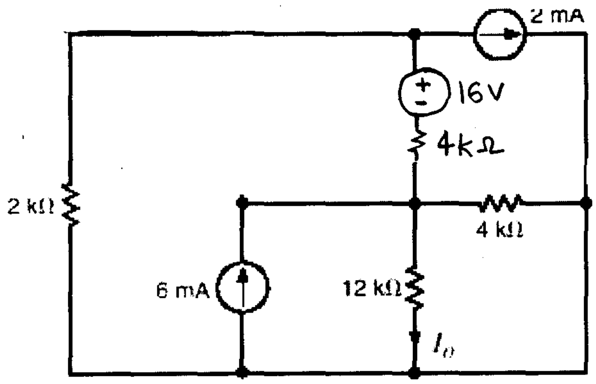
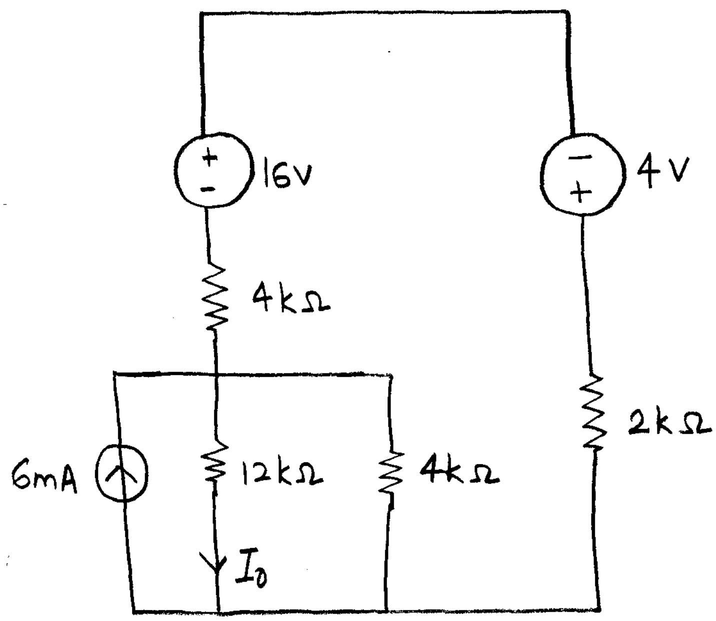
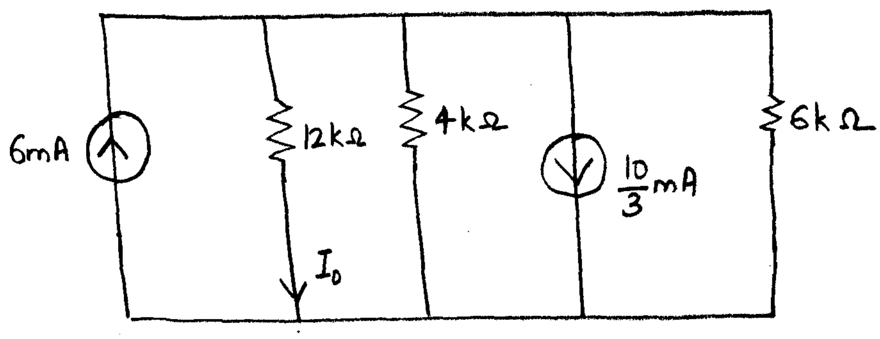


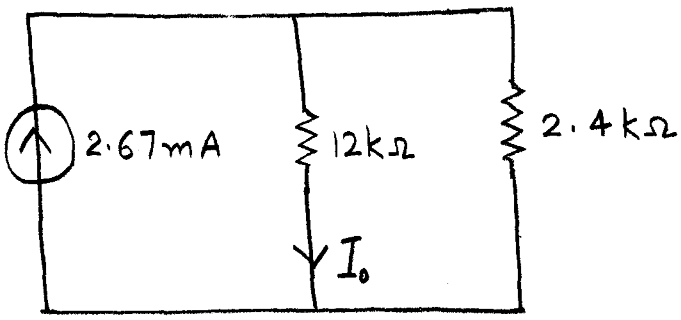
Figure P5.90

SOLUTION:









$$I_0 = \left(\frac{2.4k}{2.4k + 12k}\right)(2.667m)$$

$$= 0.444 \text{ mA}$$

5.91 Use source transformation to find I_o in the circuit in Fig. P5.91.

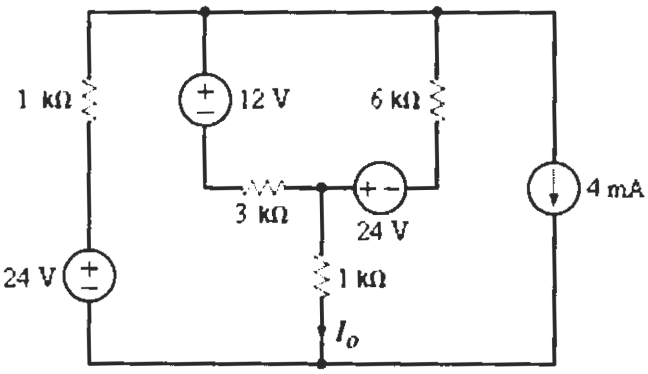
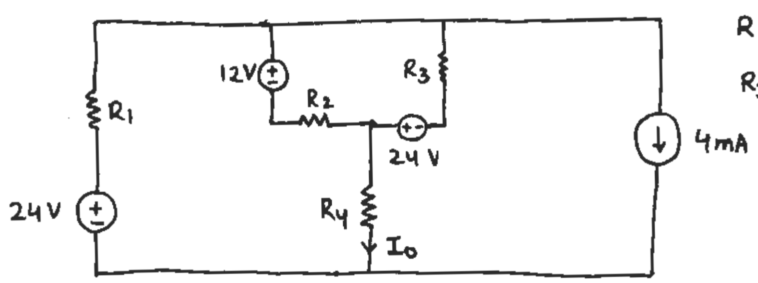


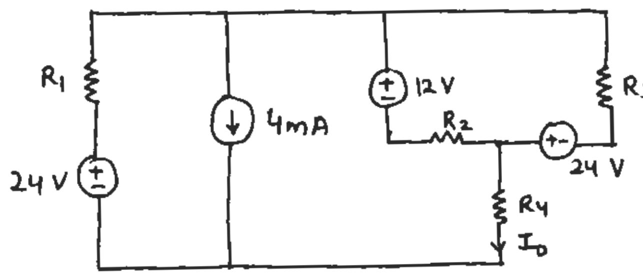
Figure P5.91

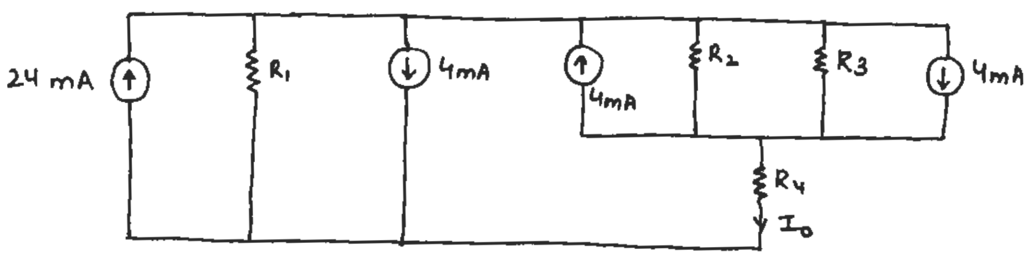
Solution: 5.91



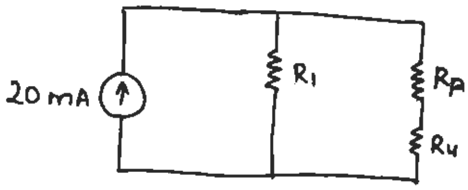
$R_1 = R_4 = 1\ k\Omega,\ R_2 = 3k\Omega,$

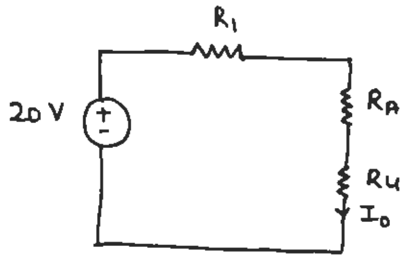
$R_3 = 6\ k\Omega$





$$R_A = R_2 \,||\, R_3 = \frac{18}{9} = 2\ k\Omega$$





$$I_o = \frac{20}{R_1 + R_A + R_4}$$

$$= \frac{20}{1+2+1}$$

$$= \frac{20}{4}$$

$$\boxed{I_o = 5\,mA}$$

5.92 Find I_o in the network in the Fig. P5.92 using source transformation.

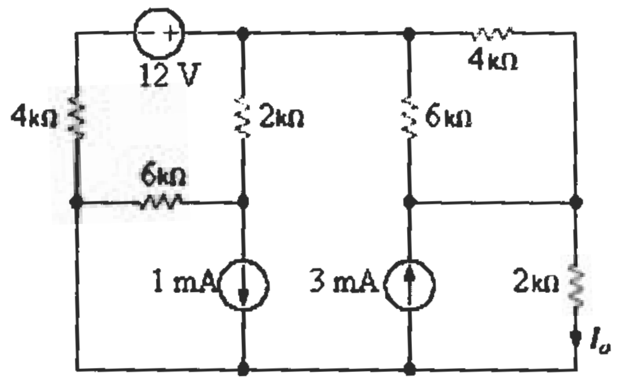
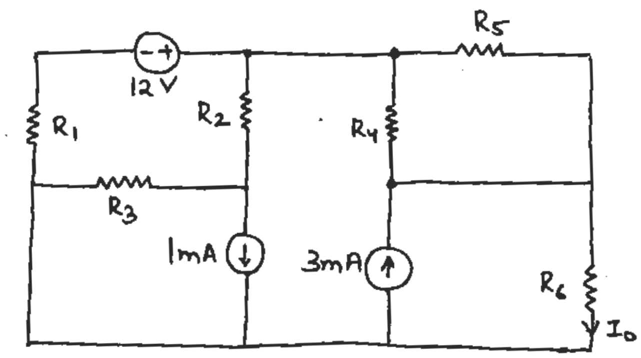


Figure P5.92

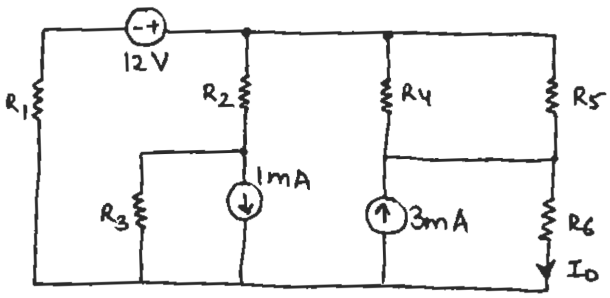
Solution: 5.92

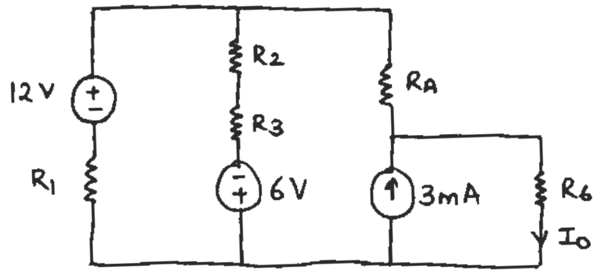


$R_1 = 4\,k\Omega$, $R_2 = 2\,k\Omega$

$R_3 = R_4 = 6\,k\Omega$,

$R_5 = 4\,k\Omega$, $R_6 = 2\,k\Omega$



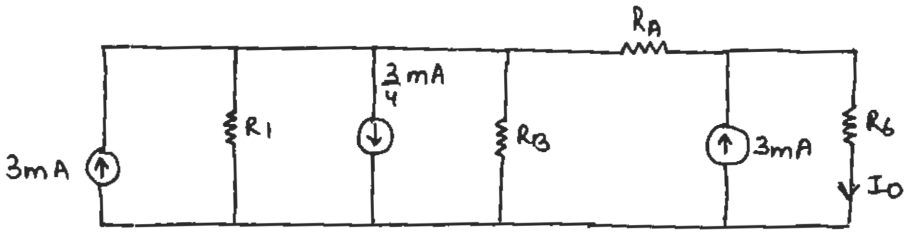


$$R_A = R_4 \,||\, R_5$$

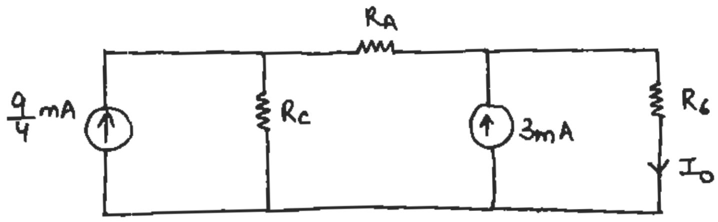
$$= \frac{24}{10} = 2.4\,k\Omega$$

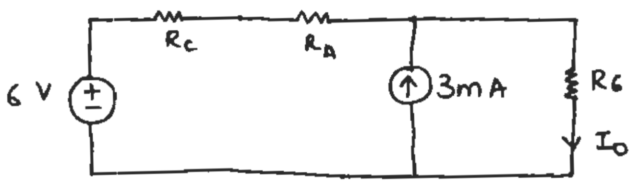
$$R_B = R_2 + R_3$$

$$= 2 + 6 = 8\,k\Omega$$



$$R_C = R_1 \parallel R_B = 4 \parallel 8 = 2.67\ k\Omega$$

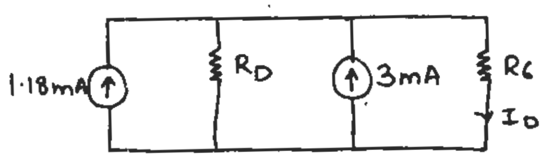


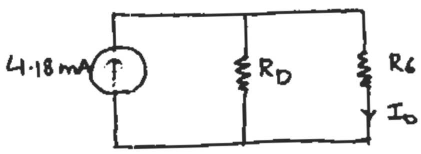


$$R_D = R_C + R_A$$

$$= \frac{32}{12} + \frac{24}{10}$$

$$= 5.07\ k\Omega$$





$$I_o = \frac{4.18 \times 10^{-3} \times 5.07}{5.07 + 2}$$

$$\boxed{I_O = 3mA}$$

5.93 Find I_o in the network in Fig. P5.93 using source transformation.

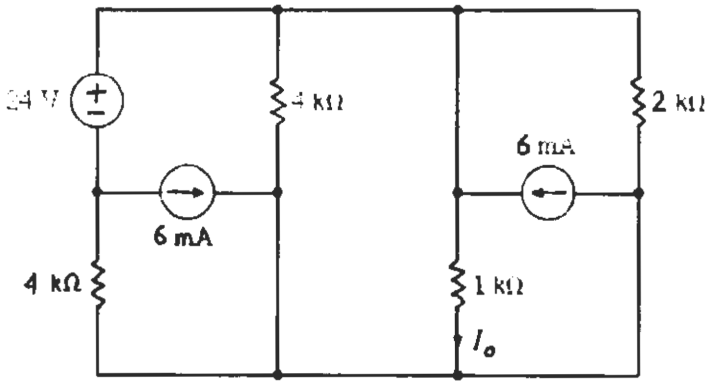
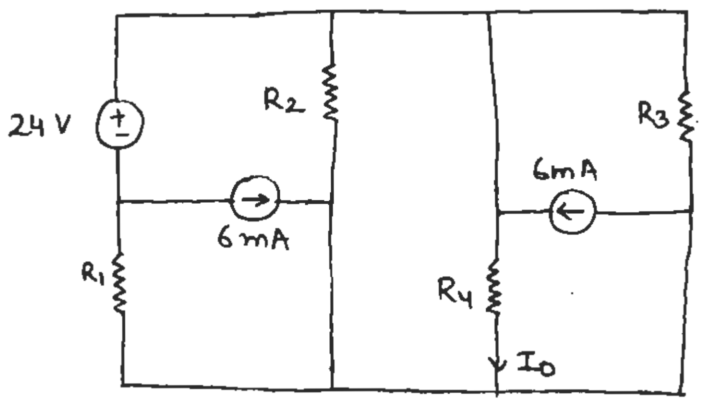


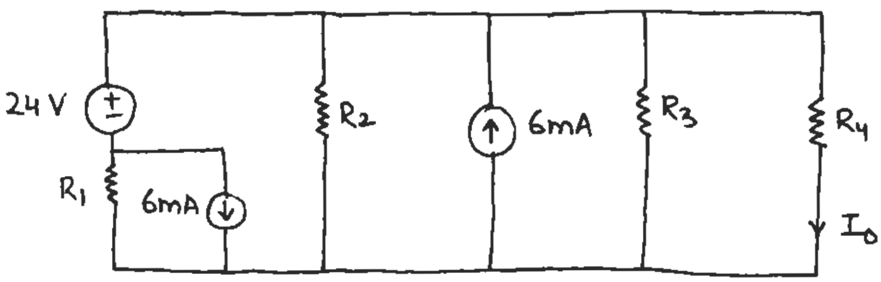
Figure P5.93

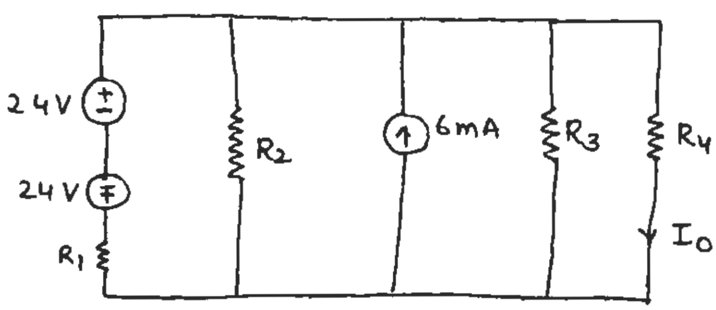
Solution: 5.93



$R_1 = R_2 = 4\,k\Omega,$

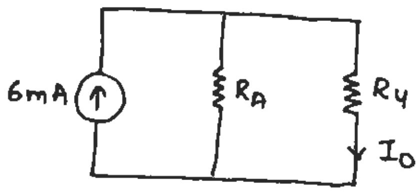
$R_3 = 2k\Omega,\ R_4 = 1\,k\Omega$





$R_1 = 4\,k\Omega$, $R_2 = 4\,k\Omega$, $R_3 = 2\,k\Omega$

$$R_A = R_1 \,||\, R_2 \,||\, R_3$$
$$= 1\,k\Omega$$



$$I_o = 6\times10^{-3} \cdot \frac{R_A}{R_A + R_4}$$
$$= 6 \cdot \frac{1}{2}$$
$$\boxed{I_o = 3\,mA}$$

5.94 Find R_L in the network in Fig. P5.94 in order to achieve maximum power transfer.

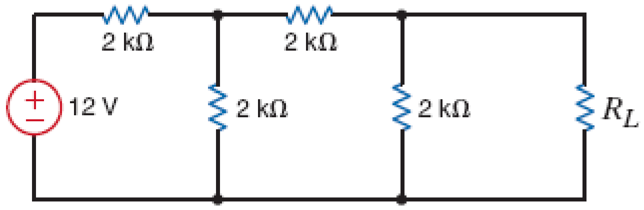
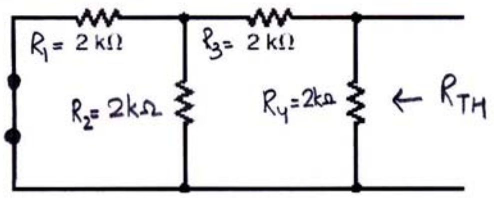


Figure P5.94

SOLUTION:



$$R_{TH} = \left[(R_1 || R_2) + R_3\right] || R_4 = 3k || 2k = 1.2 k\Omega$$

For maximum power transfer,

$$R_L = R_{TH} = 1.2 k\Omega$$

5.95 In the network in Fig. P5.95 find R_L for maximum power transfer and the maximum power transferred to this load.

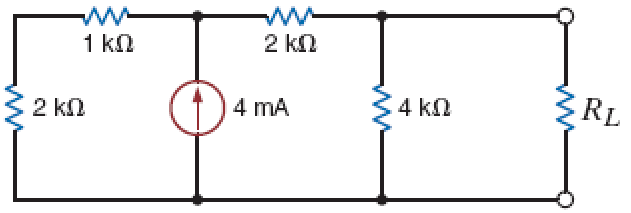
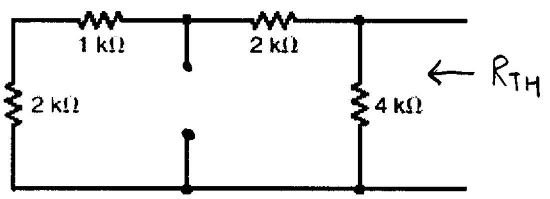
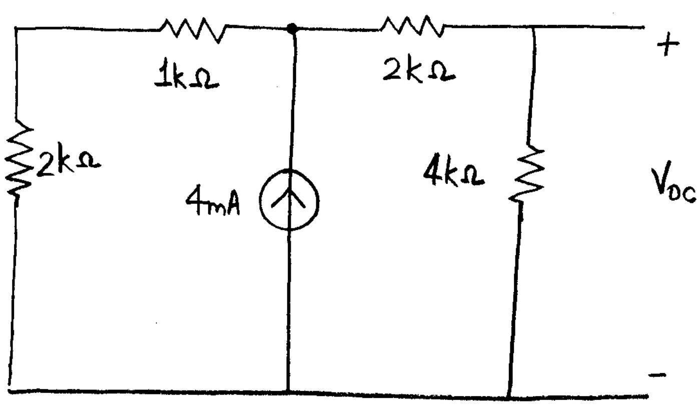


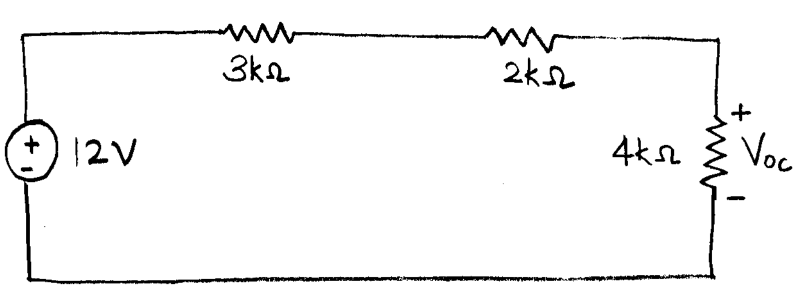
Figure P5.95

SOLUTION:



$$R_{TH} = (2k + 1k + 2k) \| 4k = 2.22k\Omega$$



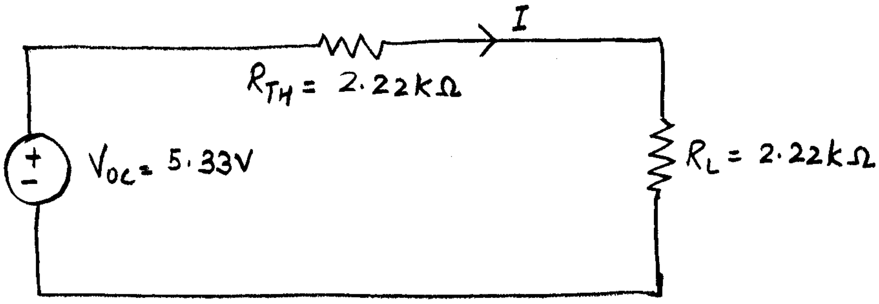


$$V_{oc} = \left(\frac{4k}{3k + 2k + 4k}\right)(12)$$

$$= 5.33V$$

For maximum power transfer,

$$R_L = R_{TH} = 2.22\,k\Omega$$



$$I = \frac{5.33}{2.22k + 2.22k}$$

$$= 1.2mA$$

$$P_L = I^2 R_L = (1.2m)^2 (2.22k)$$

$$= 3.2mW$$

5.96 Find R_L for maximum power transfer and the maximum power that can be transferred to the load in Fig. P5.96.

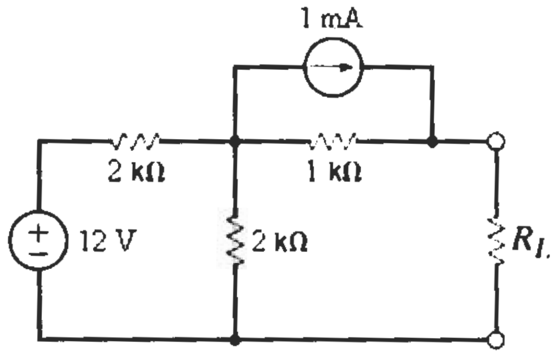
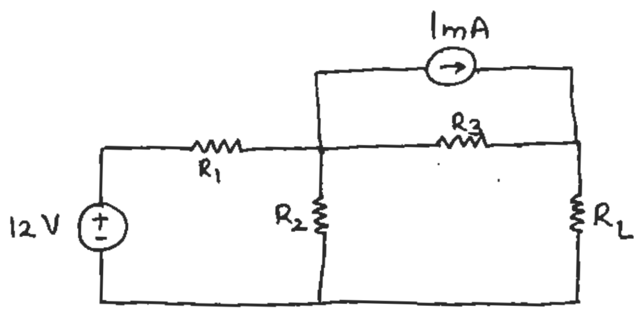


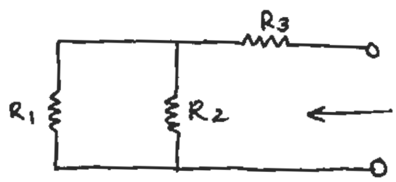
Figure P5.96

Solution: 5.96



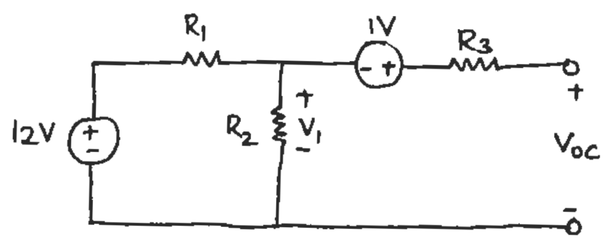
$R_1 = R_2 = 2k\Omega,$

$R_3 = 1k\Omega$



$R_{Th} = (R_1 \| R_2) + R_3$

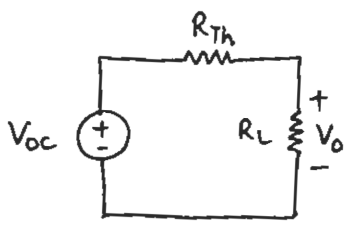
$$\boxed{R_{Th} = 2k\Omega}$$



(source Transformation)

$$V_1 = 12 \cdot \frac{R_2}{R_1 + R_2} = 6\,V, \quad V_{oc} = 1 + V_1$$

$$V_{oc} = 7\,V$$



For maximum Power Transfer $V_o = \frac{V_{oc}}{2}$

and $R_L = R_{Th}$

$$P_L = \frac{V_o^2}{R_L} = \frac{V_{oc}^2}{4R_{Th}}$$

$$\boxed{P_L = 6.13\text{ mW}}$$

5.97 Find R_L for maximum power transfer and the maximum power that can be transferred to the load in the circuit in Fig. P5.97.

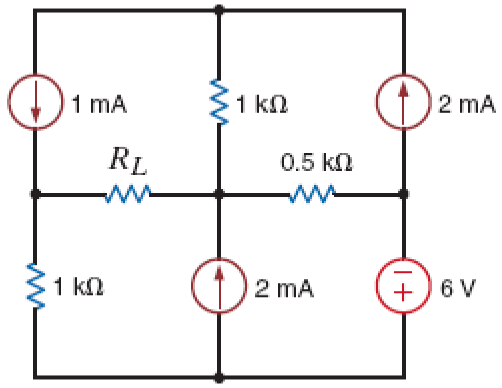
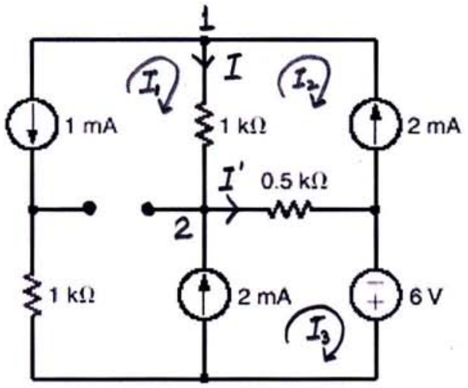


Figure P5.97

SOLUTION:



KCL at 1: $I_1 = I + I_2$

$I = I_1 - I_2$

$I_1 = -1mA$

$I_2 = -2mA$

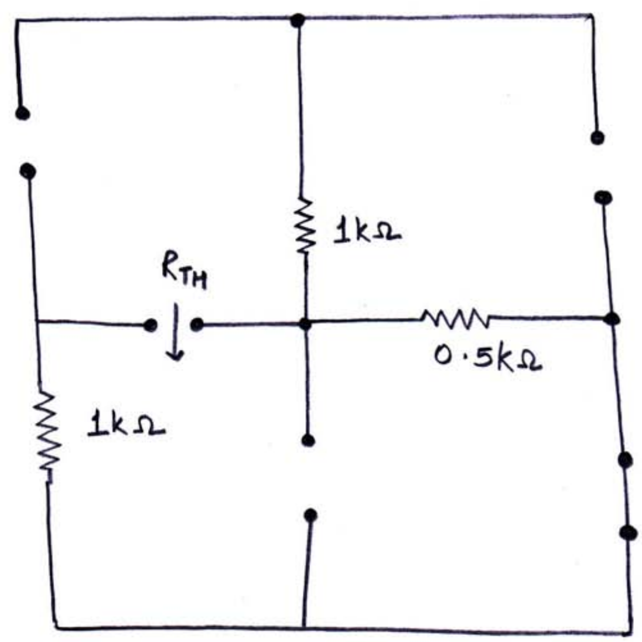
KCL at 2: $I + 2m = I'$

$I' = 3mA$

KVL around the lower loop:

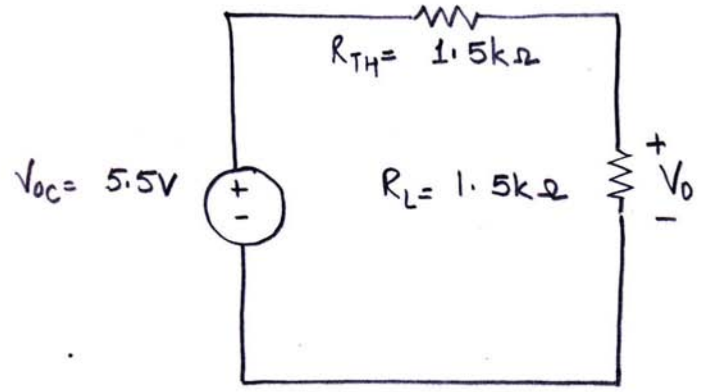
$6 = 1kI_1 + V_{OC} + 0.5k(3m)$

$V_{OC} = 5.5V$



$R_{TH} = 1.5k\Omega$

For maximum power transfer,
$R_L = R_{TH} = 1.5k\Omega$



$$V_o = \left(\frac{1.5k}{1.5k + 1.5k}\right)(5.5)$$

$$= 2.75V$$

$$P_L = \frac{V_o^2}{R_L} = \frac{(2.75)^2}{1.5k}$$

$$= 5.04mW$$

5.98 Find R_L for maximum power transfer and the maximum power that can be transferred to the load in the network in Fig. P5.98.

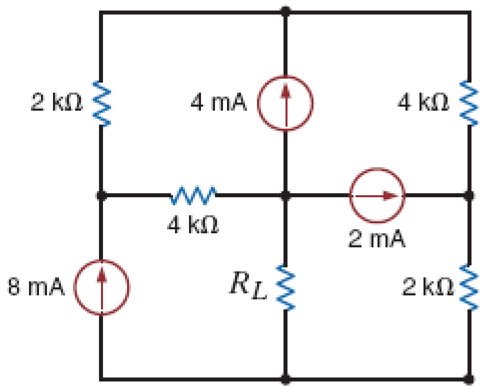
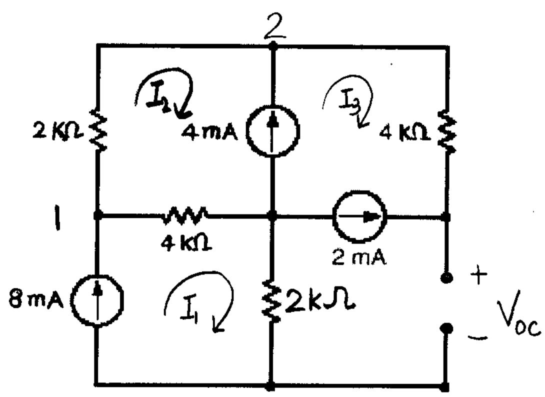


Figure P5.98

SOLUTION:



KCL at 1: $I_2 + I = 8m$

$I = 8m - I_2$

KCL at 2: $I_2 + 4m = I_3$

$I_3 = -2mA$

$I_2 = -2m - 4m = -6mA$

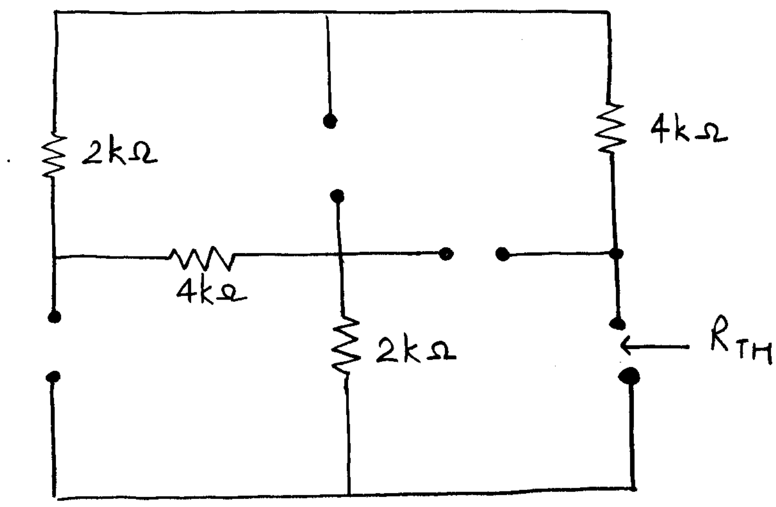
$I_1 = 8mA$

KVL: $2kI_1 + 4kI$

$= 2kI_2 + 4kI_3 + V_{oc}$

$2k(8m) + 4k(8m - I_2) = 2k(-6m) + 4k(-2m) + V_{oc}$

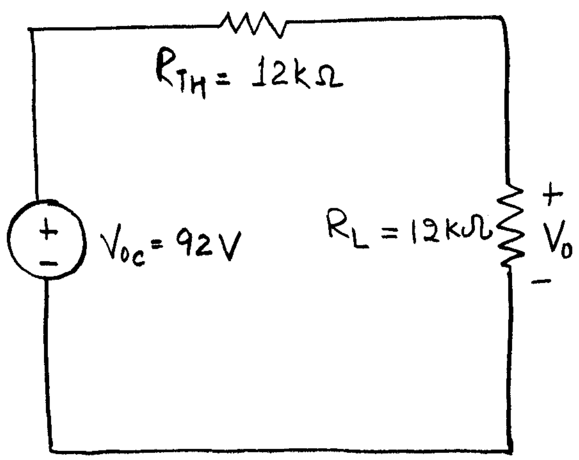
$V_{oc} = 92V$



$$R_{TH} = 2k + 4k + 2k + 4k = 12k\Omega$$

For maximum power transfer,

$$R_L = R_{TH} = 12k\Omega$$



$$V_o = \left(\frac{12k}{12k + 12k}\right)(92) = 46V$$

$$P_L = \frac{V_o^2}{R_L} = \frac{(46)^2}{12k} = 176.33\,mW$$

5.99 Find R_L for maximum power transfer and the maximum power that can be transferred to the load in the circuit in Fig. P5.99.

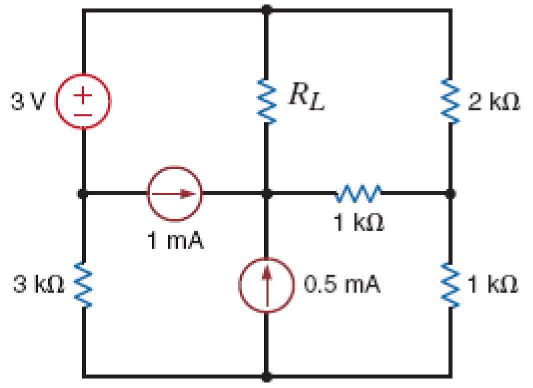
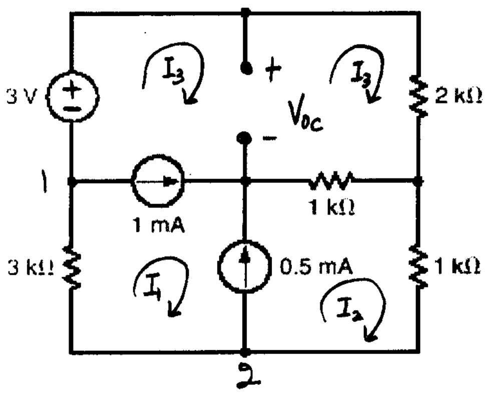


Figure P5.99

SOLUTION:



KCL at 1: $I_1 = 1m + I_3$

$I_3 = I_1 - 1m$

$V_{oc} = 2k I_3 - 1.5m(1k)$

$V_{oc} = 2k I_3 - 1.5$

KCL at 2: $I_2 = 0.5m + I_1$

$-I_1 + I_2 = 0.5m$

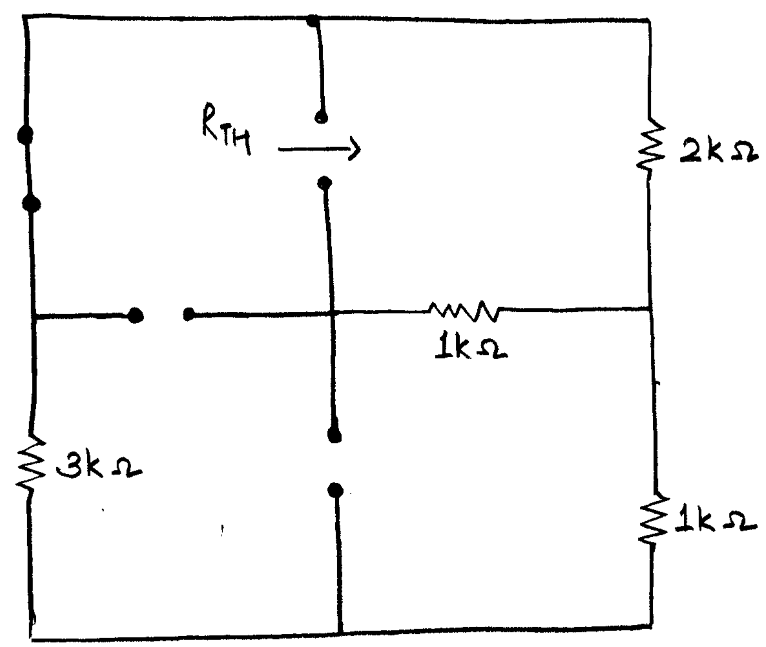
KVL around outer loop:

$3 = 3k I_1 + 1k I_2 + 2k I_3$

$3 = 3k I_1 + 1k I_2 + 2k(I_2 - 1.5m)$

$3k I_1 + 3k I_2 = 6$

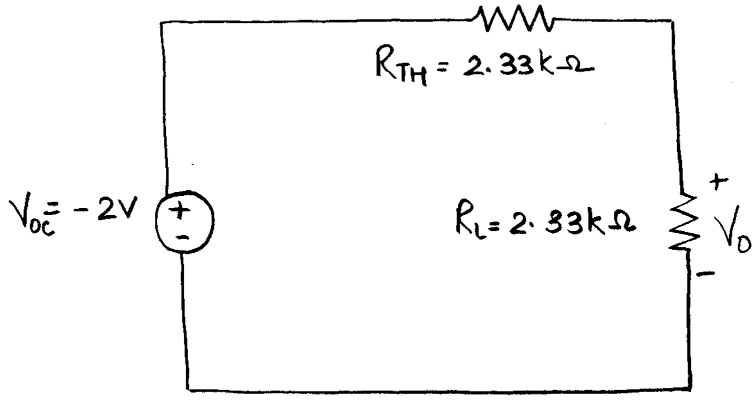
$$-I_1 + I_2 = 0.5m$$
$$I_1 = 0.75mA$$
$$I_2 = 1.25mA$$
$$I_3 = 0.75m - 1m = -0.25mA$$
$$V_{oc} = 2k(-0.25m) - 1.5$$
$$= -2V$$



$$R_{TH} = \left[(3k + 1k) \| 2k\right] + 1k = 2.33k\Omega$$

For maximum power transfer,

$$R_L = R_{TH} = 2.33k\Omega$$



$$V_o = \left(\frac{2.33k}{2.33k + 2.33k}\right)(-2) = -1V$$

$$P_L = \frac{V_o^2}{R_L} = \frac{(-1)^2}{2.33k} = 0.429mW$$

5.100 Choose R_L in Fig. P5.100 for maximum power transfer.

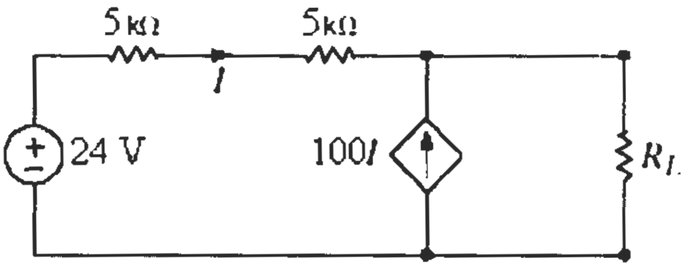
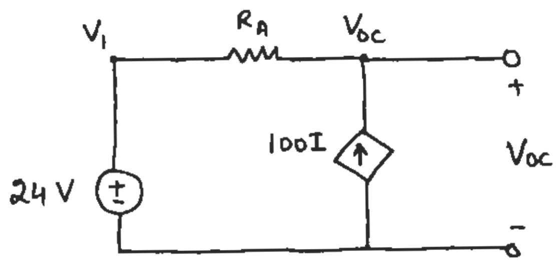


Figure P5.100

Solution: 5.100



$R_1 = R_2 = 5k\Omega$

$$R_A = R_1 + R_2 = 10k\Omega$$

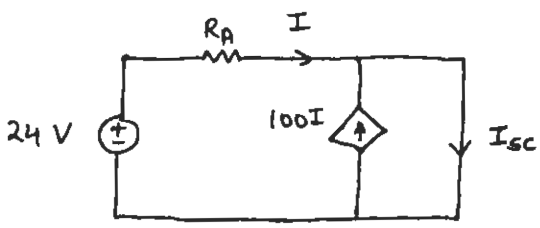
$$V_1 = 24\ V$$

$$\text{KCL @ } V_{oc}: \quad \frac{V_{oc} - V_1}{R_A} - 100I = 0$$

$$\Rightarrow \quad I - 100I = 0$$

$$\Rightarrow \quad I = 0$$

$$V_{oc} - V_1 = 0 \quad \Rightarrow V_{oc} = V_1 = 24\ V$$



$$I_{sc} = I + 100I = 101I$$

$$I = \frac{24}{10 \times 10^3} = 2.4\ mA$$

$I_{sc} = 242.4 \text{ mA}$

$$R_{Th} = \frac{V_{oc}}{I_{sc}} = 99\ \Omega$$

For maximum power transfer, $\boxed{R_L = 99\ \Omega}$

5.101 Find R_L for maximum power transfer and the maximum power that can be transferred to the load in Fig. P5.101.

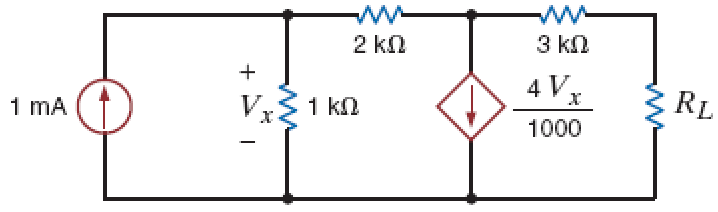
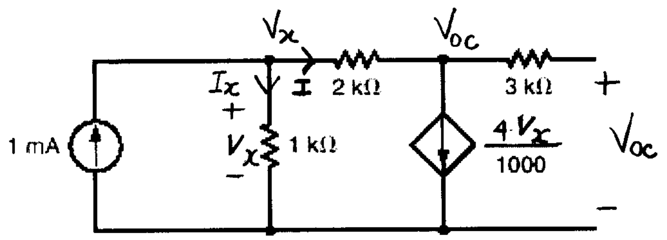


Figure P5.101

SOLUTION:



KCL at V_x: $1m = \dfrac{V_x}{1k} + \dfrac{V_x - V_{oc}}{2k}$

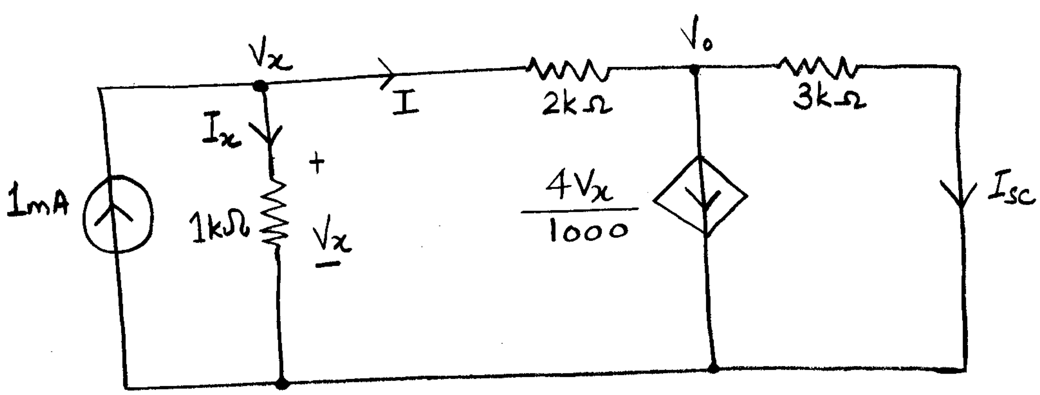
$$3V_x - V_{oc} = 2$$

KCL at V_{oc}: $\dfrac{V_x - V_{oc}}{2k} = \dfrac{4V_x}{1000}$

$$7V_x + V_{oc} = 0$$

$$V_x = 0.2\text{V}$$

$$V_{oc} = -1.4\text{V}$$



KCL at V_x: $1m = \dfrac{V_x}{1k} + \dfrac{V_x - V_o}{2k}$

$$3V_x - V_o = 2$$

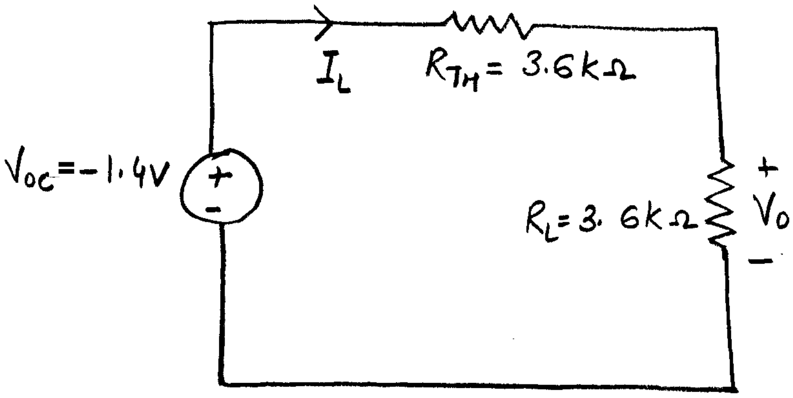
KCL at V_o: $\dfrac{V_x - V_o}{2k} = \dfrac{4V_x}{1000} + \dfrac{V_o}{3k}$

$$21V_x + 5V_o = 0$$
$$V_x = 0.278\,V$$
$$V_o = -1.167\,V$$

$$I_{sc} = \frac{V_o}{3k} = -\frac{1.167}{3k} = -0.389\,mA$$

$$R_{TH} = \frac{-1.4}{-0.389m} = 3.6\,k\Omega$$

For maximum power transfer,
$R_L = R_{TH} = 3.6\,k\Omega$.



$$I_L = \frac{-1.4}{3.6k + 3.6k}$$

$$= -0.194\,mA$$

$$P_L = I_L^2 R_L = (-0.194)^2(3.6k) = 0.136\,mW$$

5.102 Find the value of R_L in the network in Fig. P5.102 for maximum power transfer.

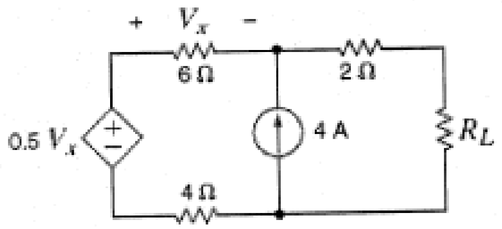
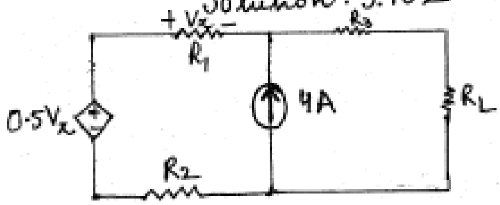


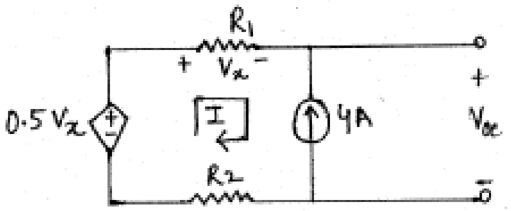
Figure P5.102

Solution: 5.102



$R_1 = 6\,\Omega,\ R_2 = 4\,\Omega$

$R_3 = 2\,\Omega$

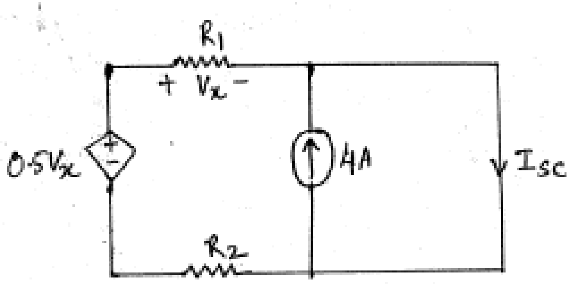


$$0.5V_x = 6I + V_{oc} + 4I$$

$$I = -4A,\ V_x = 6I = (-24)$$

$$-12 = -24 + V_{oc} - 16$$

$$V_{oc} = 28V$$



$$0.5V_x = 6I + 4I$$

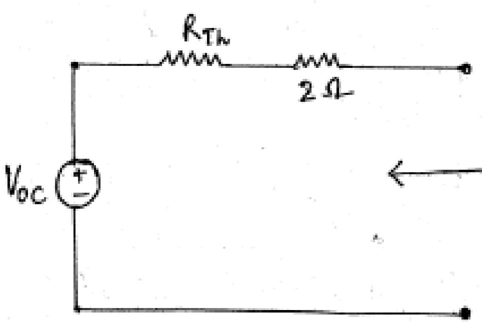
$$0.5(6I) = 10I$$

$$I = 0A$$

$$\Rightarrow V_x = 0V$$

$$I_{sc} = I + 4 = 4A$$

$$R_{Th} = \frac{V_{oc}}{I_{sc}} = \frac{28}{4} = 7\,\Omega$$



$$R_{eq} = R_{Th} + 2\,\Omega = 9\,\Omega$$

For maximum power transfer $R_L = R_{eq} = 9\,\Omega$

5.103 Find the value of R_L for maximum power transfer and the maximum power that can be transferred to R_L in the circuit of Fig. P5.103.

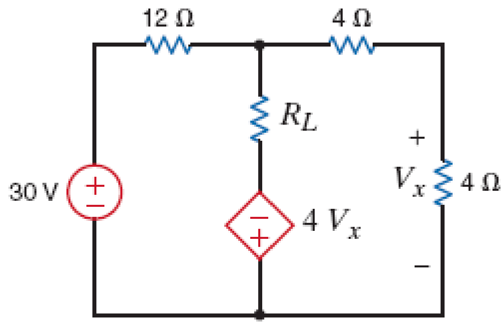
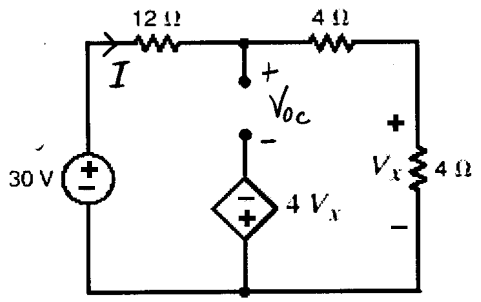


Figure P5.103

SOLUTION:



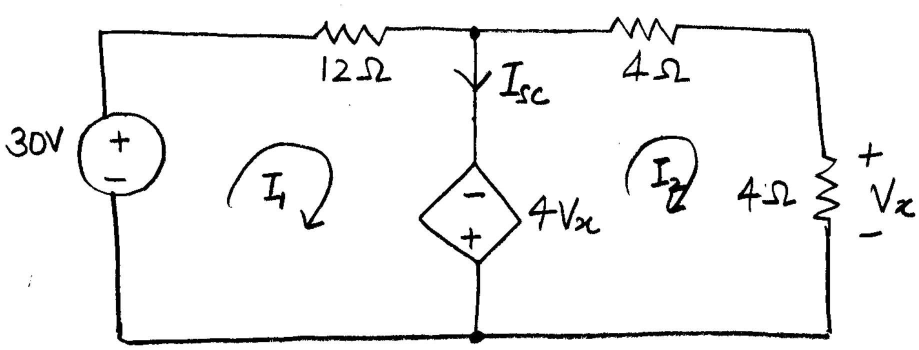
$$V_x = \left(\frac{4}{4+4+12}\right)(30) = 6V$$

$$I = \frac{30}{12+8} = 1.5A$$

KVL around left loop:

$$30 + 4V_x = 12I + V_{oc}$$

$$V_{oc} = 36V$$



$$I_{SC} = I_1 - I_2$$
$$V_x = 4I_2$$

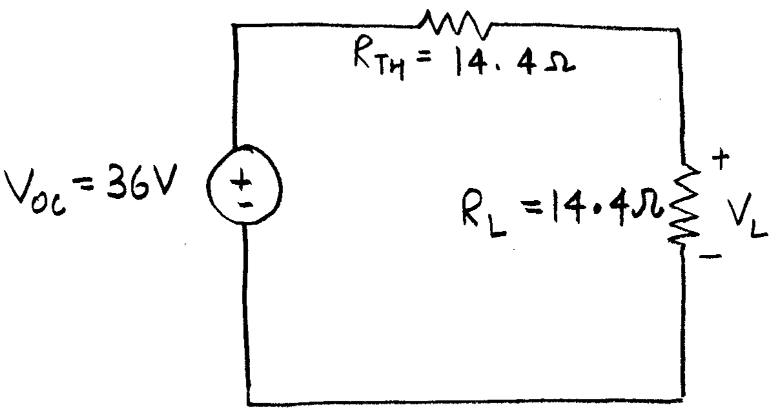
KVL around left loop:

$$30 + 4V_x = 12I_1$$
$$12I_1 - 16I_2 = 30$$

KVL around outer loop:

$$30 = 12I_1 + 8I_2$$
$$I_1 = 2.5A$$
$$I_2 = 0A$$

$$R_{TH} = \frac{36}{2.5} = 14.4\,\Omega$$



$$V_L = \left(\frac{14.4}{14.4 + 14.4}\right)(36) = 18V$$

$$P_L = \frac{V_L^2}{R_L} = \frac{(18)^2}{14.4} = 22.5W$$

5.104 Find the maximum power that can be transferred to R_L in the network of Fig. P5.104.

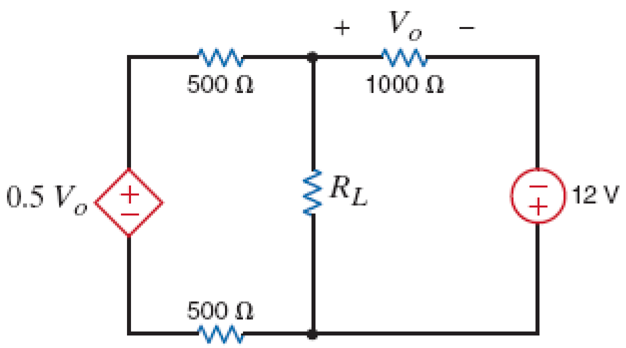
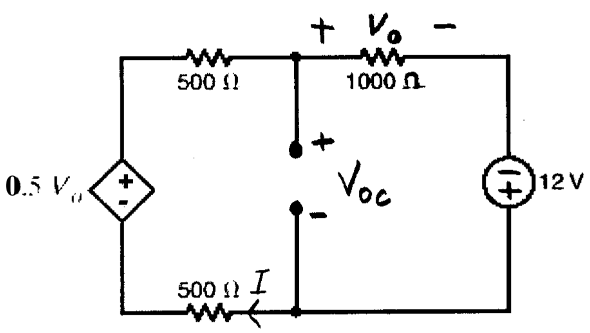


Figure P5.104

SOLUTION:



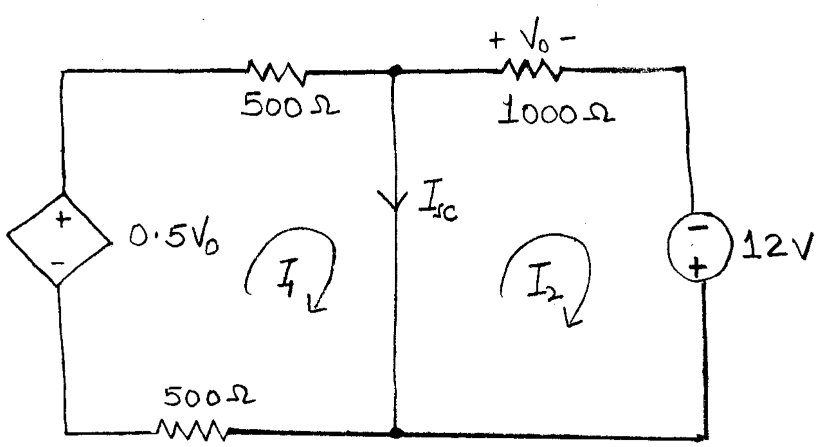
$V_0 = 1000I$

$0.5V_0 + 12 = 500I + 500I + V_0$

$I = 8mA$

$V_{oc} + 12 = 1000I$

$V_{oc} = -4V$



$I_{sc} = I_1 - I_2$

KVL around the left loop:

$0.5V_0 = 500I_1 + 500I_1$

$V_0 = 2000I_1$

KVL right loop: $V_0 = 12V$

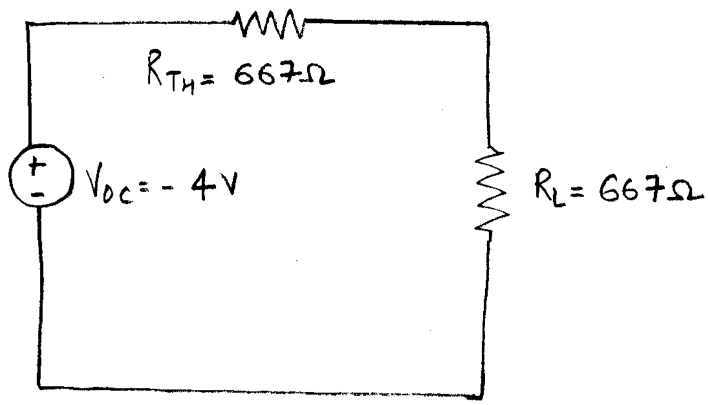
KVL right loop: $12 = 1000 I_2$

$I_2 = 12mA$

$I_1 = \frac{V_0}{2000} = \frac{12}{2000} = 6mA$

$I_{sc} = I_1 - I_2 = 6m - 12m = -6mA$

$R_{TH} = \frac{V_{oc}}{I_{sc}} = \frac{-4}{-6m} = 667\Omega$



$R_L = R_{TH} = 667\Omega$ for maximum power transfer.

$V_L = \left(\frac{667}{667+667}\right)(-4) = -2V$

$P_L = \frac{V_L^2}{R_L} = \frac{(-2)^2}{667} = 6mW$

5.105 Find the value of R_L for maximum power transfer in the circuit in Fig. P5.105.

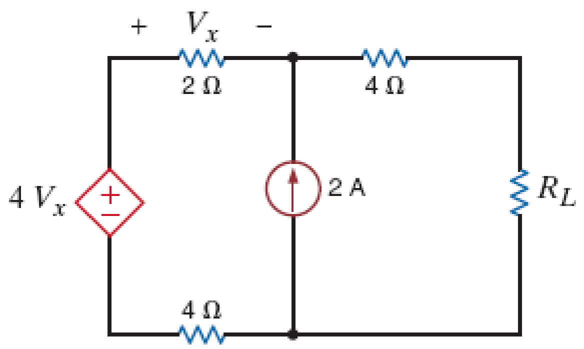
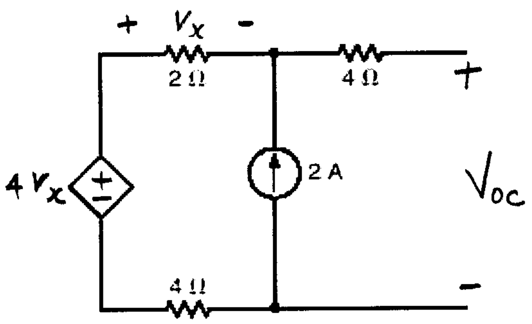
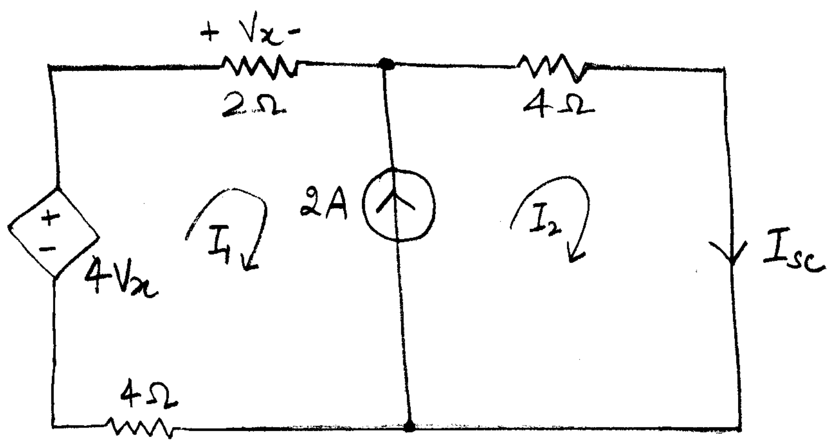


Figure P5.105

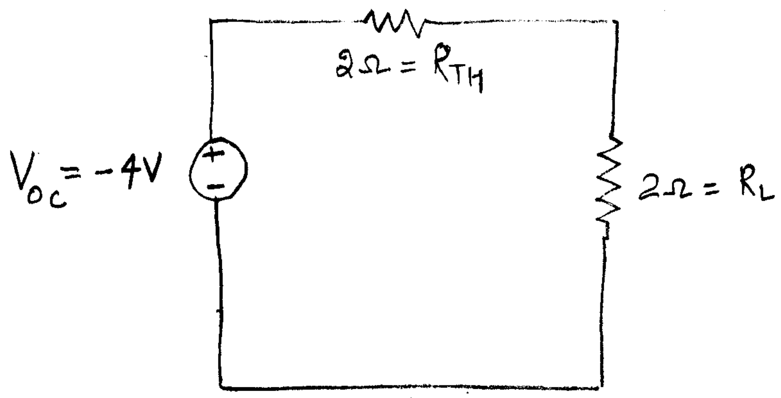
SOLUTION:



$$V_x = -2(2) = -4\text{V}$$
$$V_{oc} = 4V_x - V_x + 4(2)$$
$$V_{oc} = 4(-4) + 4 + 4(2)$$
$$V_{oc} = -4\text{ V}$$



$$I_1 + 2 = I_2$$
$$-I_1 + I_2 = 2$$
$$4V_x = 4I_1 + V_x + 4I_2$$
$$V_x = 2I_1$$
$$-2I_1 + 4I_2 = 0$$
$$I_1 = -4A$$
$$I_2 = -2A$$
$$I_{sc} = I_2 = -2A$$



$$R_{TH} = \frac{V_{oc}}{I_{sc}} = \frac{-4}{-2} = 2\,\Omega$$

$R_L = R_{TH} = 2\,\Omega$ for maximum power transfer.

5.106 In the network of Fig. P5.106. find the value of R_L for maximum power transfer. In addition, calculate the power dissipated in R_L under these conditions.

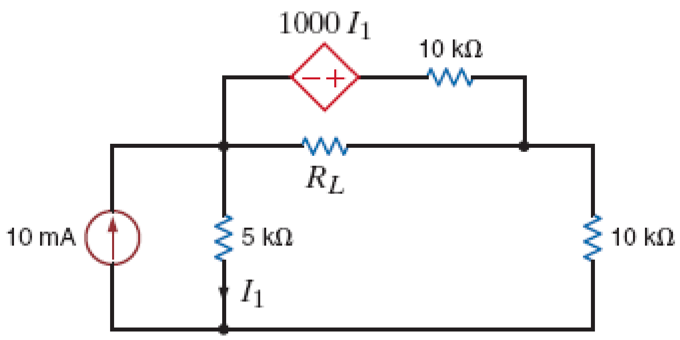
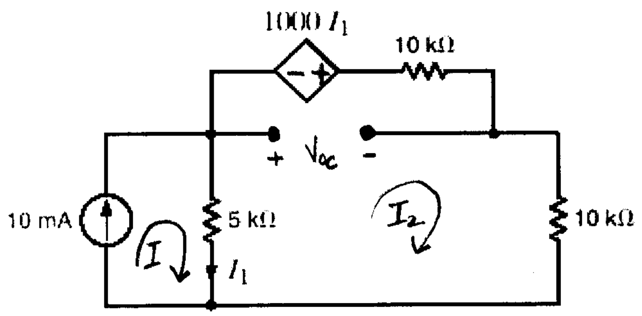


Figure P5.106

SOLUTION:



$$KCL:\ 10m = I_1 + I_2$$

$$1000 I_1 - 10k\, I_2 - 10k\, I_2 + 5k\, I_1 = 0$$

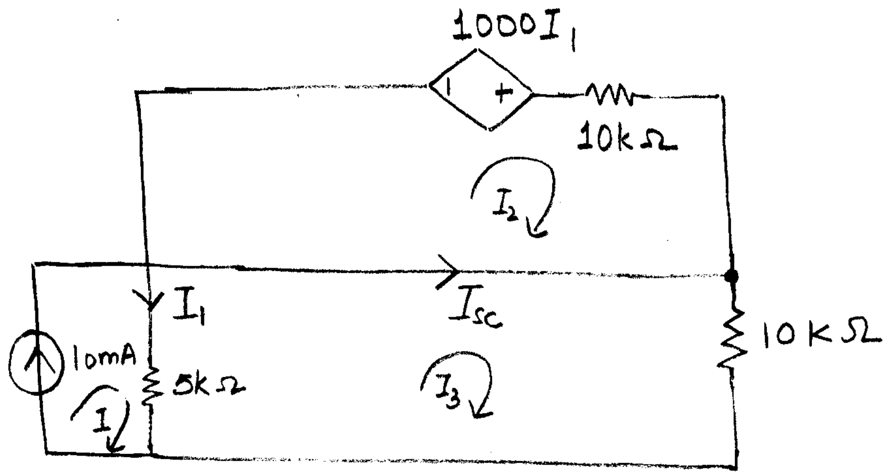
$$1000(10m - I_2) - 20k\, I_2 + 5k\, I_1 = 0$$

$$10 - 21000 I_2 + 50 - 5000 I_2 = 0$$

$$I_2 = 2.3mA$$

$$I_1 = 7.7mA$$

$$V_{oc} = 15.5V$$



$$10m = I_1 + I_3$$

$$10kI_3 - 5kI_1 = 0$$

$$I_1 = 6.67mA$$

$$I_3 = 3.33mA$$

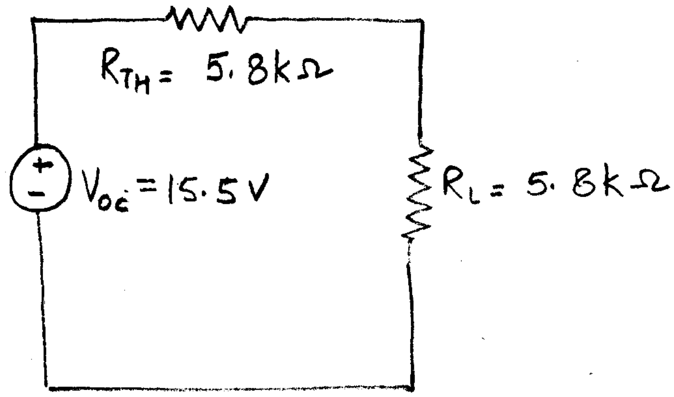
$$1000I_1 = -10k\,I_2$$

$$I_2 = 0.67mA$$

$$I_{sc} = I_3 - I_2$$

$$I_{sc} = 3.33m - 0.67m = 2.667mA$$

$$R_{TH} = \frac{15.5}{2.667} = 5.811\,k\Omega$$



$R_L = R_{TH} = 5.811 k\Omega$

$\therefore V_L = 7.75V$

$P_L = 10.33 \ mW$

5.107 Calculate the maximum power that can be transferred to R_L in the circuit in Fig. P5.107.

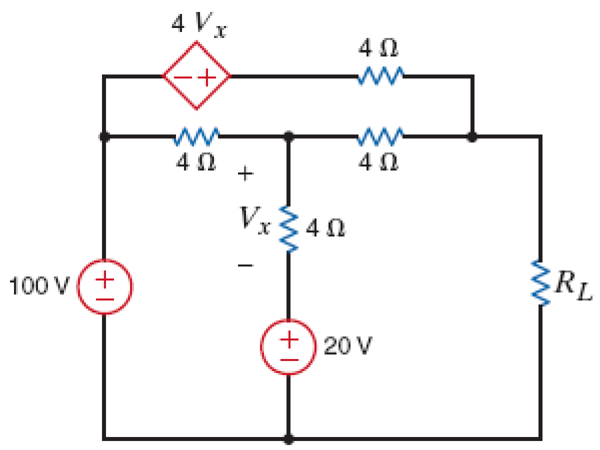
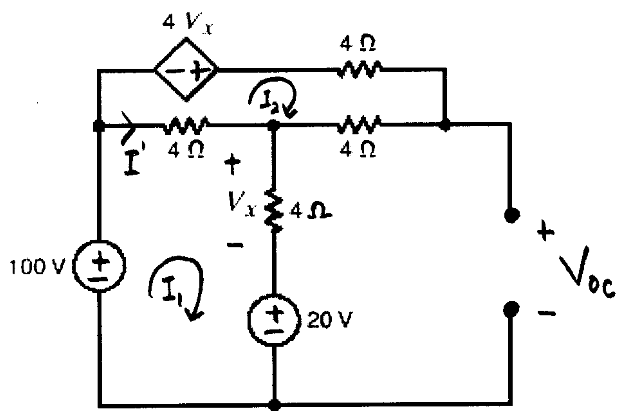


Figure P5.107

SOLUTION:



$$I' = I_1 - I_2$$

$$100 = 4I' + 4I_1 + 20$$

$$8I_1 - 4I_2 = 80$$

$$4V_x = 4I_2 + 4I_2 - 4I'$$

$$V_x = 4I_1$$

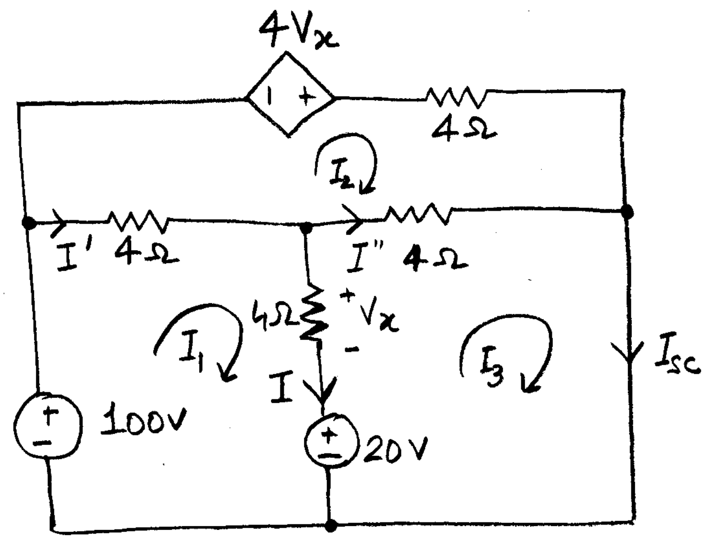
$$-20I_1 + 12I_2 = 0$$

$$I_1 = 60\text{A}$$

$$I_2 = 100\text{A}$$

$$V_{oc} = 20 + 4I_1 + 4I_2$$

$V_{oc} = 660V$



$I_3 = I_{sc}$

$I' = I_1 - I_2$

$I = I_1 - I_3$

$V_x = 4I = 4(I_1 - I_3)$

$100 + 4V_x = 4I_2$

$16I_1 - 4I_2 - 16I_3 = -100$

$100 = 4I' + 4I + 20$

$8I_1 - 4I_2 - 4I_3 = 80$

$100 = 4I' + 4I''$

$I'' = I_3 - I_2$

$4I_1 - 8I_2 + 4I_3 = 100$

$I_1 = 60A$

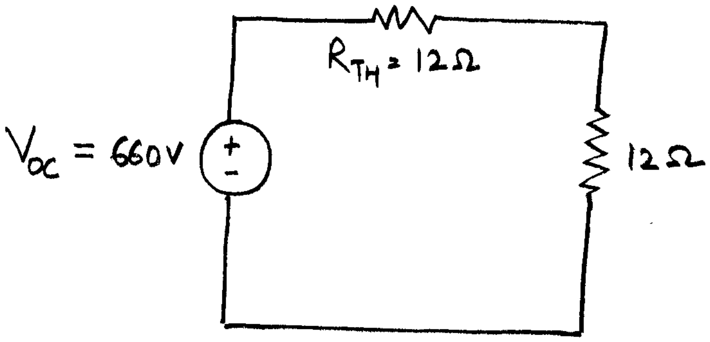
$I_2 = 45A$

$I_3 = 55A$

$I_{sc} = 55A$

$R_{TH} = \dfrac{660}{55} = 12\Omega$

$R_L = R_{TH} = 12\,\Omega$ for maximum power transfer.



$$I_L = \frac{660}{12+12} = 27.5A$$

$$P_L = I_L^2 R_L = (27.5)^2(12) = 9075W$$

5.108 Find R_L for maximum power transfer and the maximum power that can be transferred in the network in Fig. P5.108.

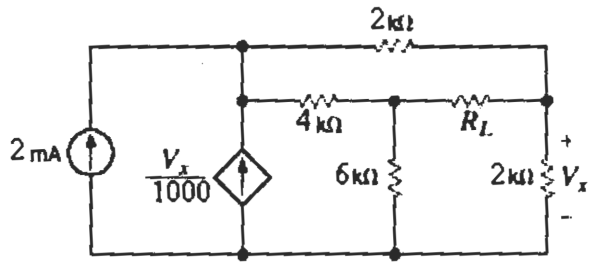
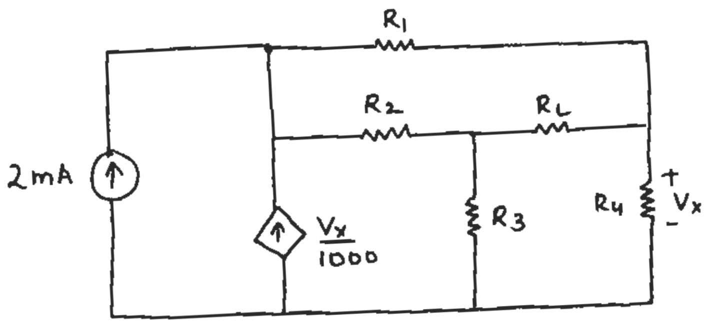
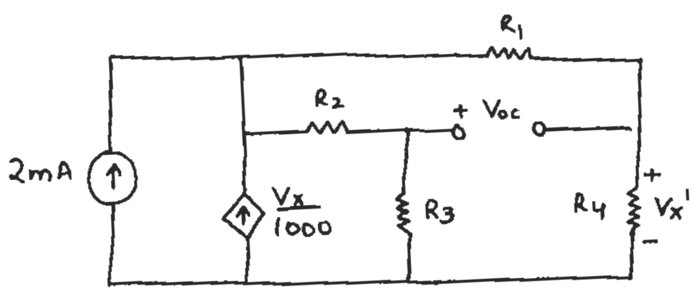


Figure P5.108

Solution: 5·108



$$R_1 = R_4 = 2\,k\Omega \quad , \quad R_2 = 4\,k\Omega \; , \; R_3 = 6\,k\Omega$$



$$\text{KCL @ } V_1 : \quad -2\times10^{-3} - \frac{V_x'}{1000} + \frac{V_1}{R_2+R_3} + \frac{V_1}{R_1+R_4} = 0$$

$$2V_x' = \frac{7}{20}V_1 \qquad \text{———} \qquad (1)$$

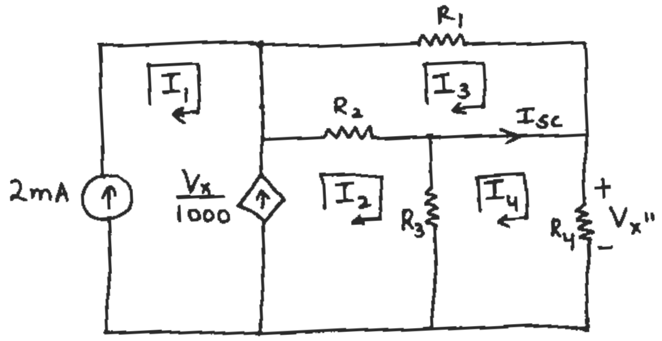
$$\text{Also} \quad V_x' = V_1 \cdot \frac{R_4}{R_1+R_4} = \frac{V_1}{2}$$

Substituting $V_x' = \frac{V_1}{2}$ in equation (1)

$$V_1 = -13.3\text{ V} \Rightarrow V_x' = -6.67\text{ V}$$

$$V_2 = V_1 \frac{R_2}{R_2+R_3} = -8\text{ V}$$

$$V_{oc} = V_2 - V_x' = -1.33\text{ V} \quad \text{—— } (2)$$



$I_1 = 2\text{mA}$ $\qquad V_x'' = I_4 R_4$

$$I_2 - I_1 = \frac{V_x''}{1000}$$

$$I_2 = \frac{I_4 R_4}{1000} + 2\times10^{-3}$$

KVL @ I_4 : $I_4(R_3+R_4) - I_2 R_3 = 0$

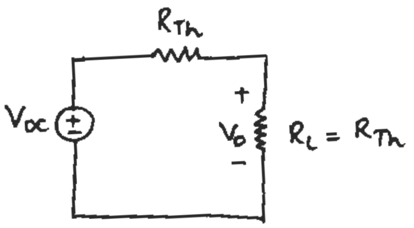
$$I_4 = -3\text{ mA}$$

KVL @ I_3 : $I_3(R_1+R_2) - I_2 R_2 = 0$

$$I_3 = -2.67\text{ mA}$$

$$I_{sc} = I_4 - I_3 = -0.333\text{ mA}$$

$$R_{Th} = \frac{V_{oc}}{I_{sc}} \Rightarrow \boxed{R_{Th} = 4.00\text{ k}\Omega}$$



$$P_o = \frac{V_{oc}^2}{4R_{Th}}$$

$$\boxed{P_o = 111\,\mu W}$$

5.109 A cell phone antenna picks up a call. If the antenna and cell phone are modeled as shown in Fig. P5.109,

(a) Find R_{cell} for maximum output power.

(b) Determine the value of P_{out}.

(c) Determine the corresponding value of P_{ant}.

(d) Find V_o/V_{ant}.

(e) Determine the amount of power lost in R_{ant}.

(f) Calculate the efficiency $\eta = P_{out}/P_{ant}$.

(g) Determine the value of R_{cell} such that the efficiency is 90%.

(h) Given the change in (g), what is the new value of P_{ant}?

(i) Given the change in (g), what is the new value of P_{out}?

(j) Comment on the results obtained in (i) and (b).

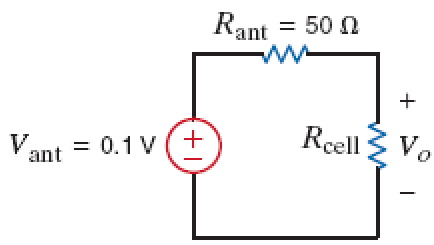
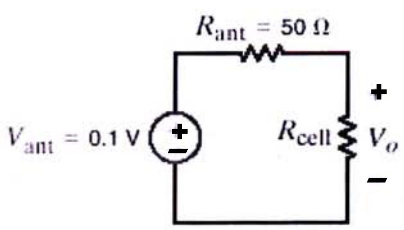


Figure P5.109

SOLUTION:



a) $R_{cell} = R_{ant} = 50\Omega$

b) $V_0 = \left(\frac{50}{50+50}\right)(0.1) = 50mV$

$$P_{out} = \frac{V_0^2}{R_{cell}} = \frac{(50m)^2}{50} = 0.05mW$$

c) $P_{out} = 2P_{out} = 0.1mW$

d) $V_o = \left(\frac{R_{cell}}{R_{cell}+R_{ant}}\right)(V_{ant})$

$$\frac{V_o}{V_{ant}} = \frac{50}{50+50} = \frac{1}{2}$$

e) $P_{R_{ant}} = P_{out} = 0.05\,mW$

f) $\eta = \frac{P_{out}}{P_{ant}} = \frac{0.05m}{0.1m} = 0.5 = 50\%$

g) $P_{out} = \frac{V_o^2}{R_{cell}}$

$$P_{ant} = \frac{V_{ant}^2}{R_{cell}+R_{ant}}$$

$$\eta = \frac{\dfrac{\left(\frac{R_{cell}}{R_{cell}+R_{ant}}\right)^2 V_{ant}^2}{R_{cell}}}{\dfrac{V_{ant}^2}{R_{cell}+R_{ant}}} = \frac{R_{cell}}{R_{cell}+R_{ant}}$$

$$0.9 = \frac{R_{cell}}{R_{cell}+50}$$

$$R_{cell} = 450\,\Omega$$

h) $P_{ant} = \frac{V_{ant}^2}{R_{cell}+R_{ant}} = \frac{(0.1)^2}{450+50} = 0.02\,mW$

i) $P_{out} = \eta P_{ant} = 0.9(0.02m) = 0.018\,mW$

j) As η increases, more power is transferred. Output power decreases as η moves from 50%.

5.110 Some young engineers at the local electrical utility are debating ways to lower operating costs. They know that if they can reduce losses, they can lower operating costs. The question is whether they should design for maximum power transfer or maximum efficiency, where efficiency is defined as the ratio of customer power to power generated. Use the model in Fig. P5.110 to analyze this issue and justify your conclusions. Assume that both the generated voltage and the customer load are constant.

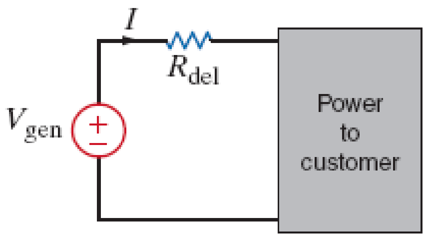
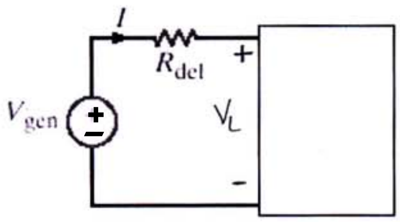


Figure P5.110

SOLUTION:



$$P_{load} = V_L I = (V_{gen} - IR_{del}) I$$

$$P_{gen} = V_{gen} I$$

$$\eta = \frac{P_{load}}{P_{gen}} = \frac{(V_{gen} - IR_{del}) I}{V_{gen} I}$$

$$\eta = \frac{V_{gen} I - I^2 R_{del}}{V_{gen} I}$$

$$\eta = 1 - \frac{I R_{del}}{V_{gen}} = 1 - k R_{del}$$

$$\text{where } k = \frac{I}{V_{gen}}$$

As $R_{del} \longrightarrow 0$, $\eta \longrightarrow 100\%$

If no power is lost in delivery, all of the power generated can be sold.

5.111 Using PSPICE, find I_o in the network in Fig. P5.111.

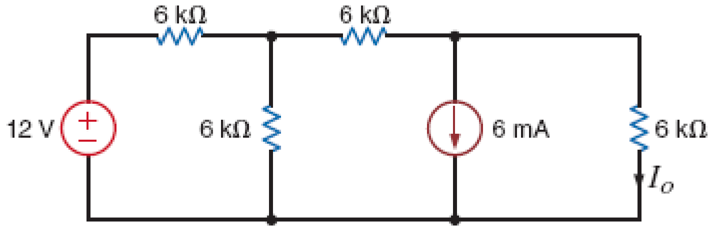
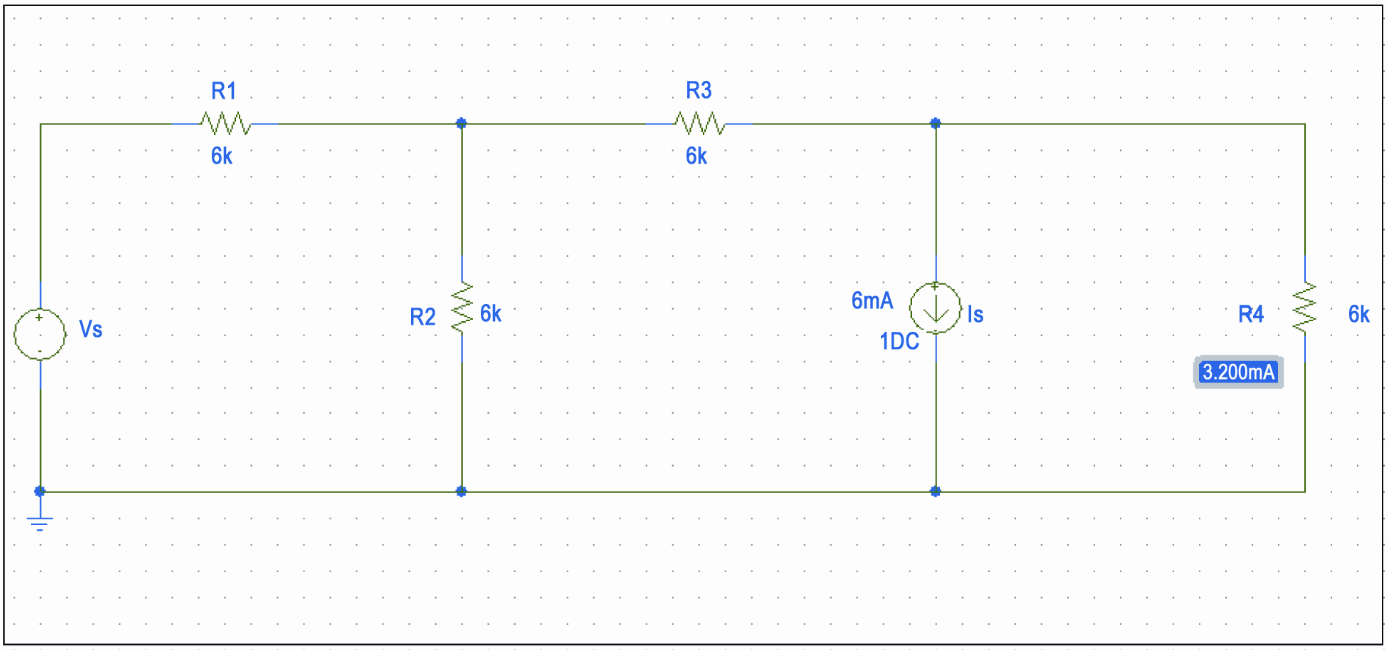
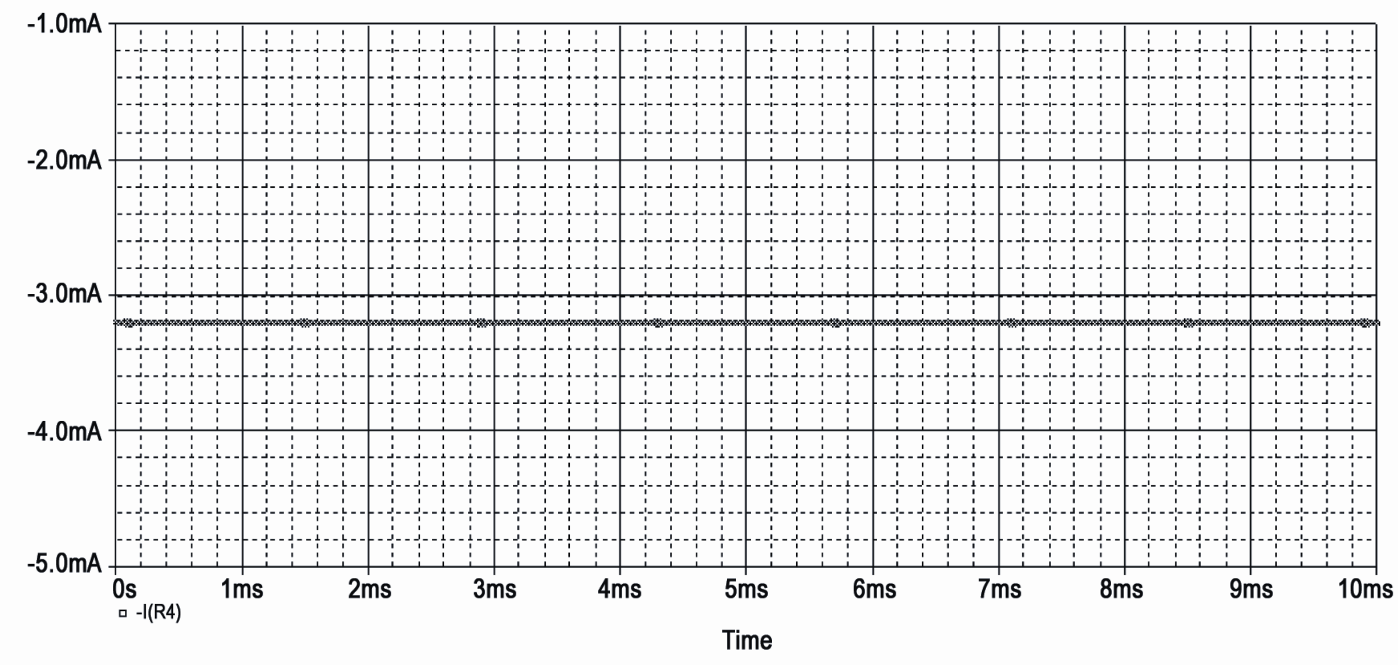


Figure P5.111

SOLUTION:




-1.0mA
-2.0mA
-3.0mA
-4.0mA
-5.0mA
0s
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10ms
-I(R4)
Time

5.112 Find V_o in the network in Fig. P5.112 using PSPICE.

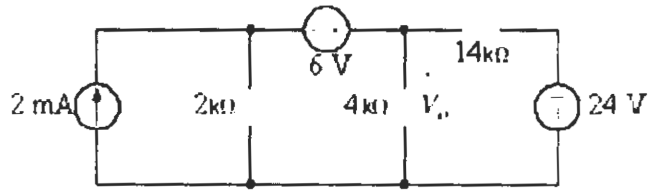
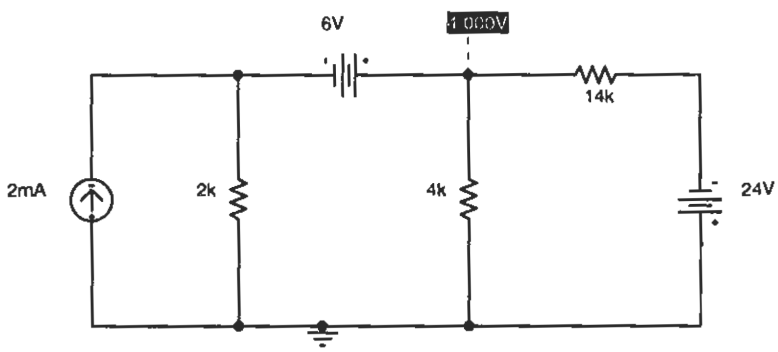


Figure P5.112

Solution: 5.112



5.113 Using PSPICE, find I_o in the circuit in Fig. P5.113.

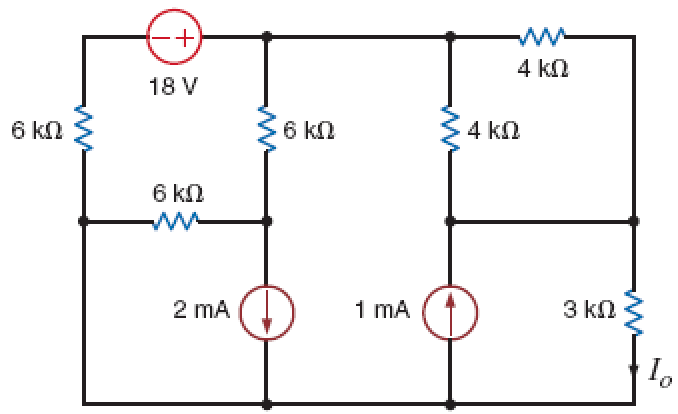
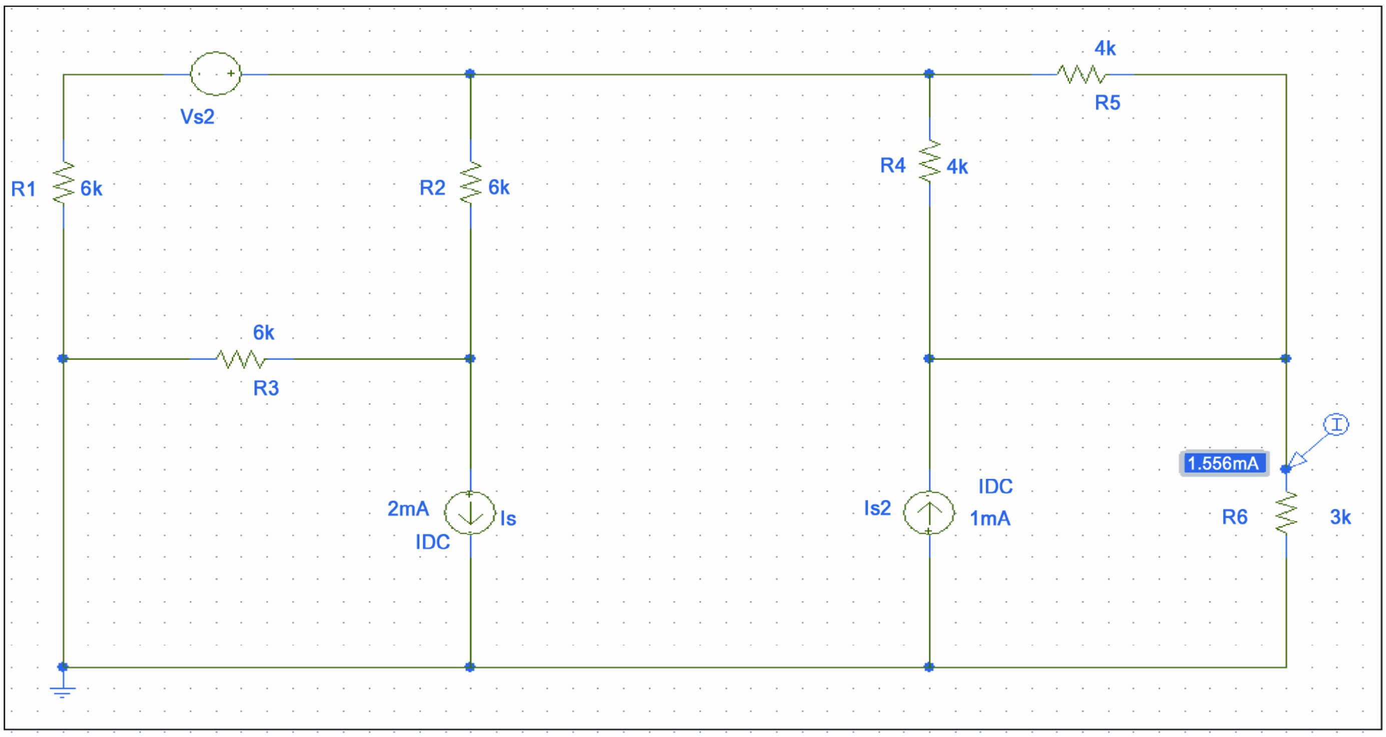
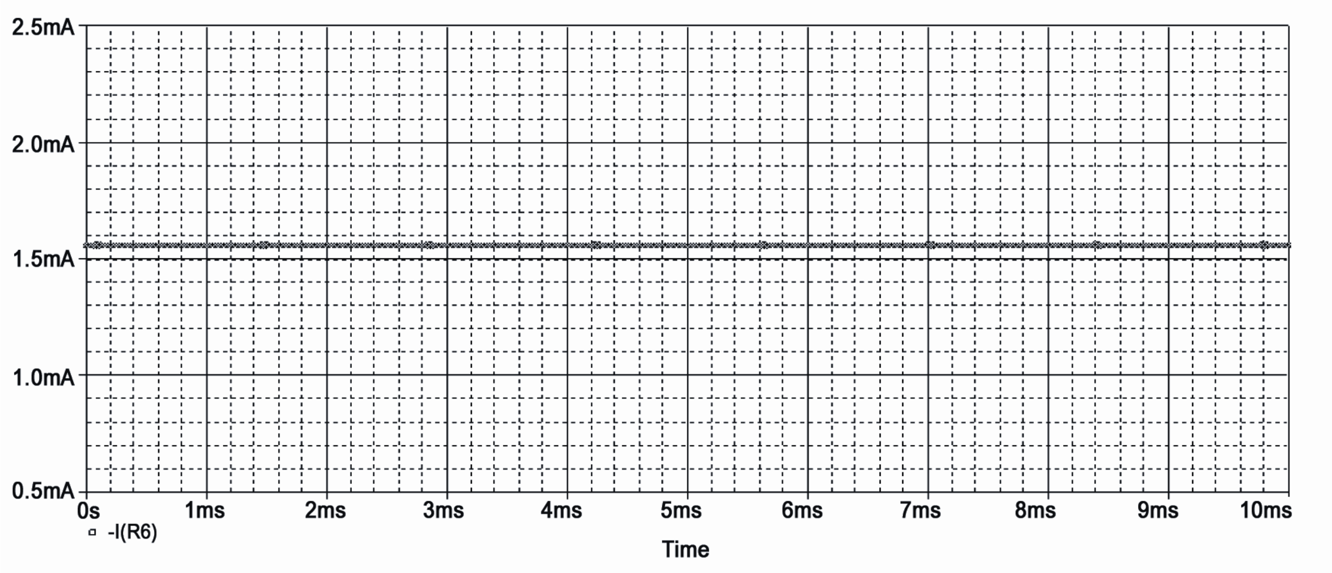


Figure P5.113

SOLUTION:




2.5mA
2.0mA
1.5mA
1.0mA
0.5mA
0s
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10ms
-I(R6)
Time

5.114 Find V_o in the network in Fig. P5.114 using PSPICE.

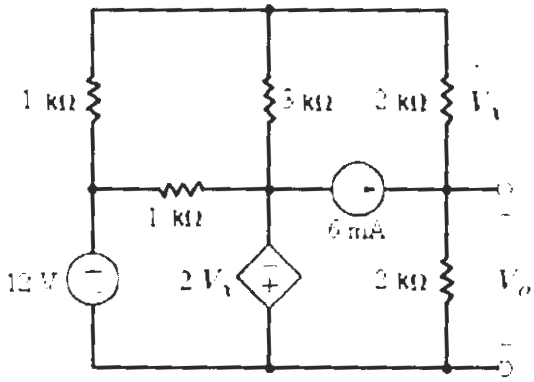
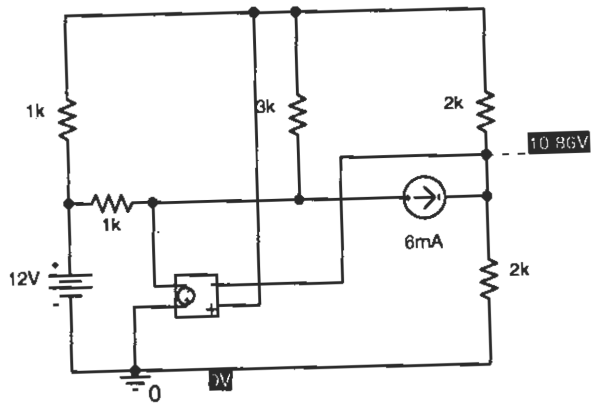


Figure P5.114

Solution: 5.114



5FE-1 Determine the maximum power than can be delivered to the load R_L in the network in Fig. 5PFE-1.

a. 2 mW
b. 10 mW
c. 4 mW
d. 8 mW

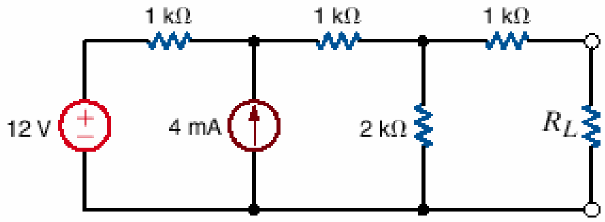
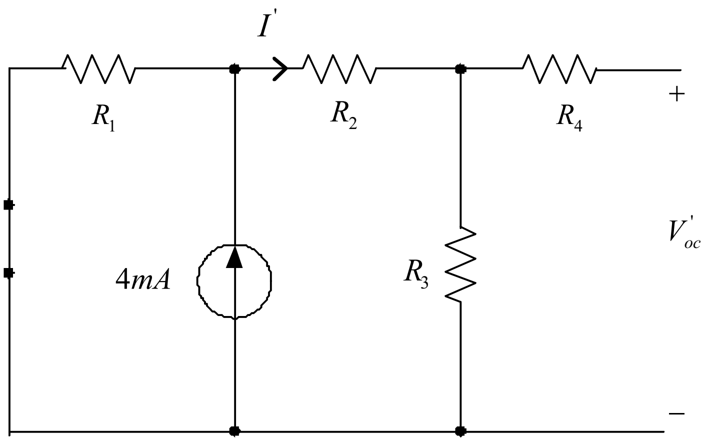


Figure 5PFE-1

SOLUTION:



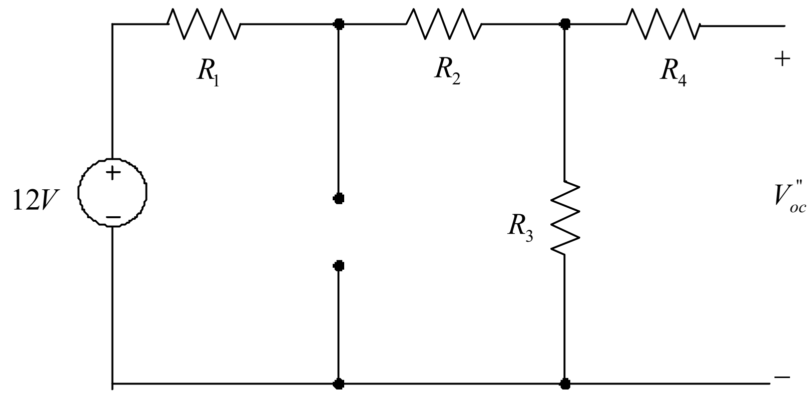
The correct answer is *d*.
Use superposition.

$$I' = \left(\frac{R_1}{R_1 + R_2 + R_3}\right)(4m)$$

$$I' = \left(\frac{1k}{1k + 1k + 2k}\right)(4m) = 1mA$$

$$V'_{oc} = I'R_3 = (1m)(2k)$$

$$V'_{oc} = 2V$$

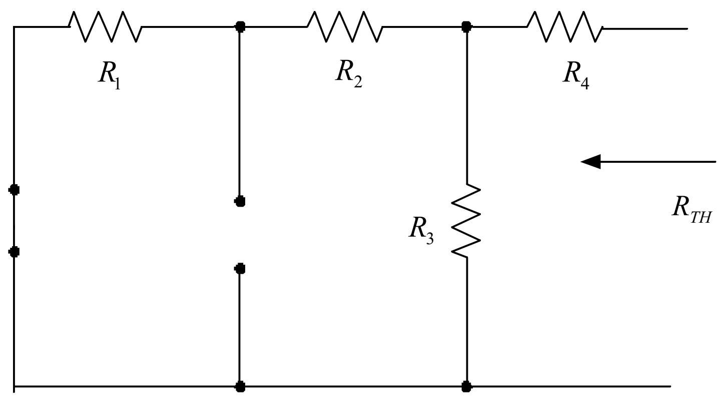


$$V_{oc}^{"} = \left(\frac{R_3}{R_1 + R_2 + R_3}\right)(12)$$

$$V_{oc}^{"} = \left(\frac{2k}{1k + 1k + 2k}\right)(12)$$

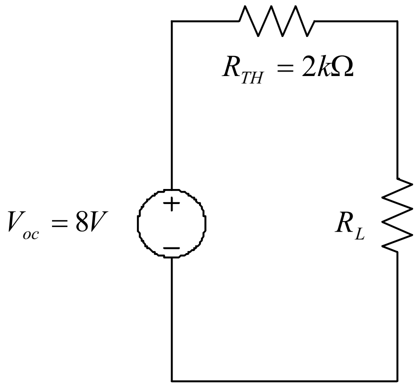
$$V_{oc}^{"} = 6V$$

$$V_{oc} = V_{oc}^{'} + V_{oc}^{"} = 2 + 6 = 8V$$



$$R_{TH} = [(R_1 + R_2)||R_3] + R_4$$

$$R_{TH} = \frac{2k(2k)}{2k + 2k} + 1k = 2k\Omega$$



$$P_{L_{\max}} = I_L^2 R_L$$

$R_L = R_{TH}$ for maximum power.

$$P_{L_{\max}} = \left(\frac{V_{oc}}{2R_{TH}}\right)^2 R_{TH}$$

$$P_{L_{\max}} = \frac{V_{oc}^2}{4R_{TH}} = \frac{8^2}{4(2k)} = 8mW$$

5FE-2 Find the value of the load R_L in the network in Fig. 5PFE-2 that will achieve maximum power transfer, and determine that value of the maximum power.

a. 22.5 mW
b. 80.4 mW
c. 64.3 mW
d. 121.5 mW

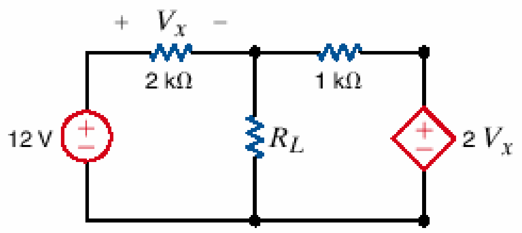
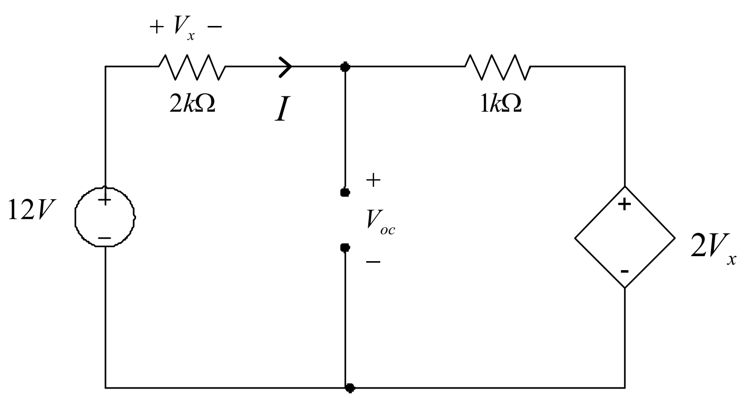


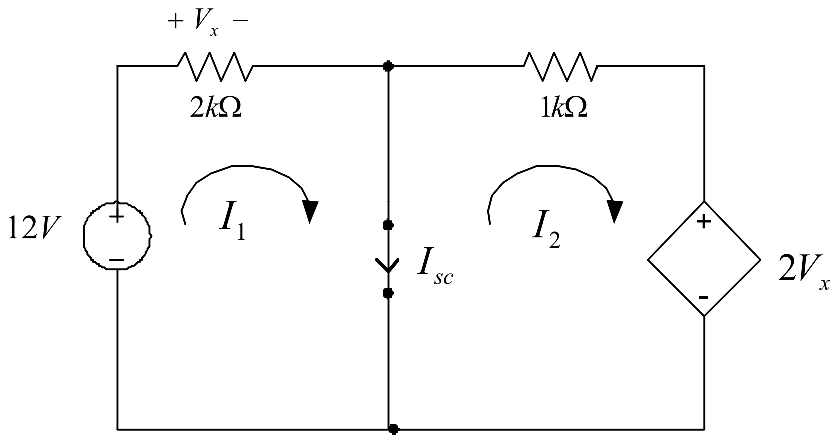
Figure 5PFE-2

SOLUTION:



The correct answer is *c*.

$$12 = 2kI + 1kI + 2V_x$$
$$V_x = I(2k)$$
$$12 = 2kI + 1kI + 2(2kI)$$
$$I = \frac{12}{7} mA$$
$$12 = 2kI + V_{oc}$$
$$12 = 2k\left(\frac{12}{7}m\right) + V_{oc}$$
$$V_{oc} = 8.57V$$

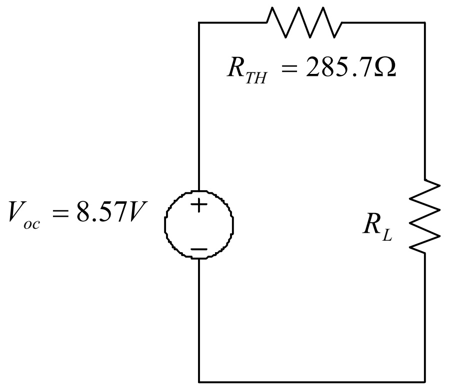


$$I_1 = \left(\frac{12}{2k}\right) = 6mA$$

$$1kI_2 + 2V_x = 0$$
$$1kI_2 + 2(2kI_1) = 0$$
$$I_2 = -24mA$$
$$I_1 = I_2 + I_{sc}$$
$$I_{sc} = 6m - (-24m) = 30mA$$

$$R_{TH} = \frac{V_{oc}}{I_{sc}} = \frac{8.57}{30m} = 285.7\Omega$$

$R_L = R_{TH}$ for maximum power.



$$P_{L_{\max}} = \frac{V_{oc}^2}{4R_{TH}} = \frac{(8.57)^2}{4(285.7)} = 64.3mW$$

5FE-3 Find the value of R_L in the network in Fig. 5PFE-3 for maximum power transfer to this load.

a. 12.92 Ω

b. 8.22 Ω

c. 6.78 Ω

d. 10.53 Ω

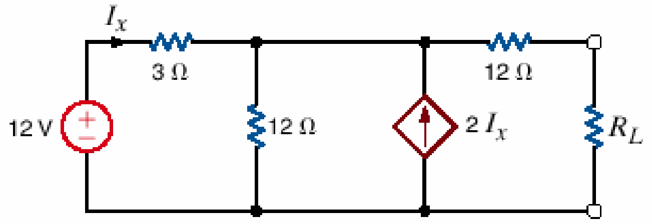
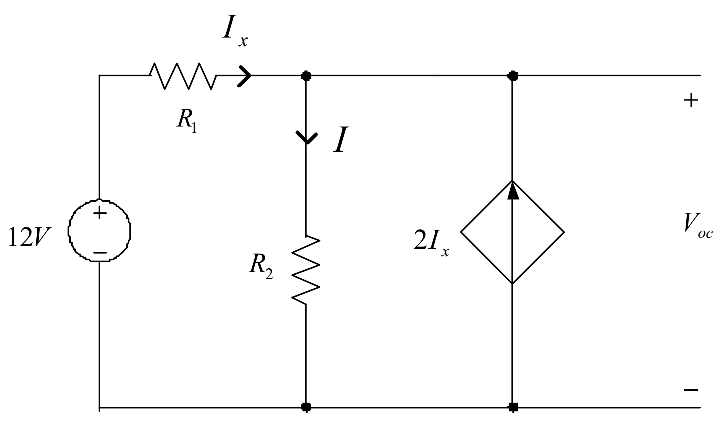


Figure 5PFE-3

SOLUTION:



The correct answer is *a*.

$$I = I_x + 2I_x$$

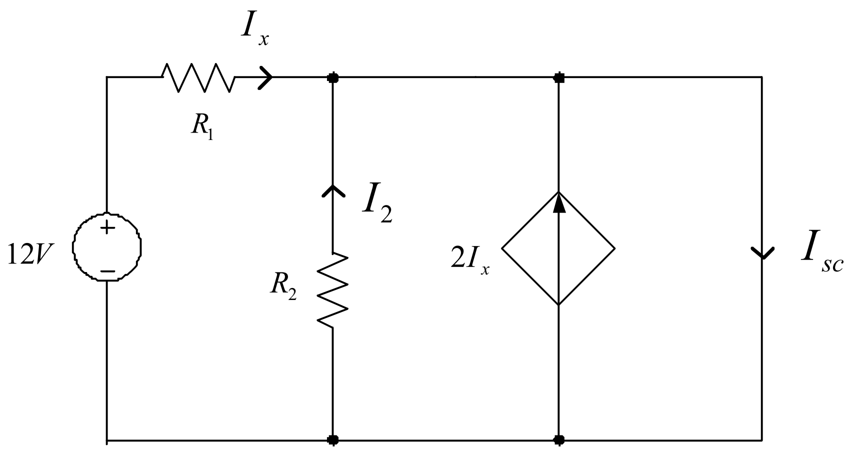
$$I = 3I_x$$

$$12 = 3I_x + 12I$$

$$12 = 3I_x + 12(3I_x)$$

$$I_x = \frac{4}{13} A$$

$$V_{oc} = 12I = 12(3I_x) = 12(3)\left(\frac{4}{13}\right) = 11.08V$$



$I_{sc} = I_x + I_2 + 2I_x = 3I_x + I_2$

$I_2 = 0A$

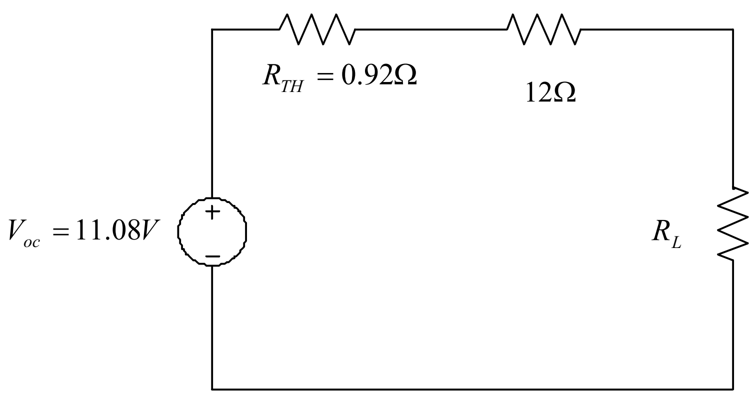
$I_{sc} = 3I_x$

$12 = 3I_x$

$I_x = 4A$

$I_{sc} = 3(4) = 12A$

$$R_{TH} = \frac{V_{oc}}{I_{sc}} = \frac{11.08}{12} = 0.92\Omega$$



$R_L = 0.92 + 12 = 12.92\Omega$

$R_L = 12.92\Omega$ for maximum power transfer.

5FE-4 What is the current I in Fig. 5PFE-4?

a. 8 A
b. −4 A
c. 0 A
d. 4 A

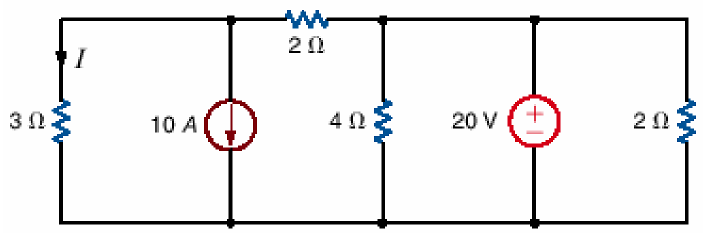
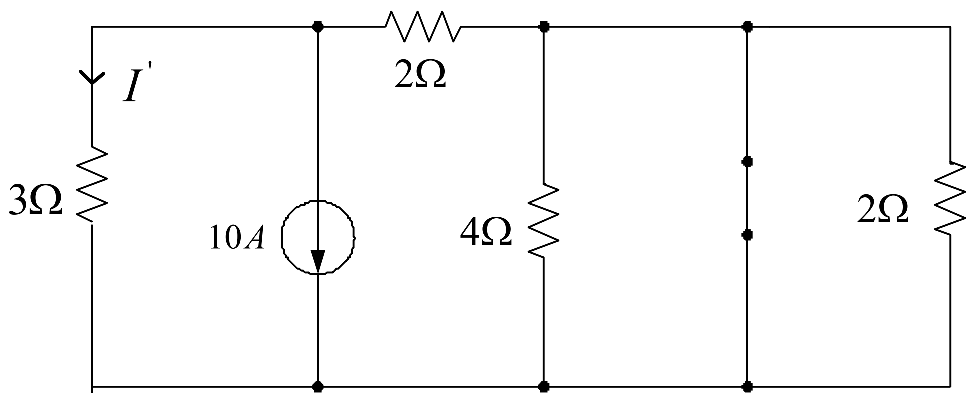


Figure 5PFE-4

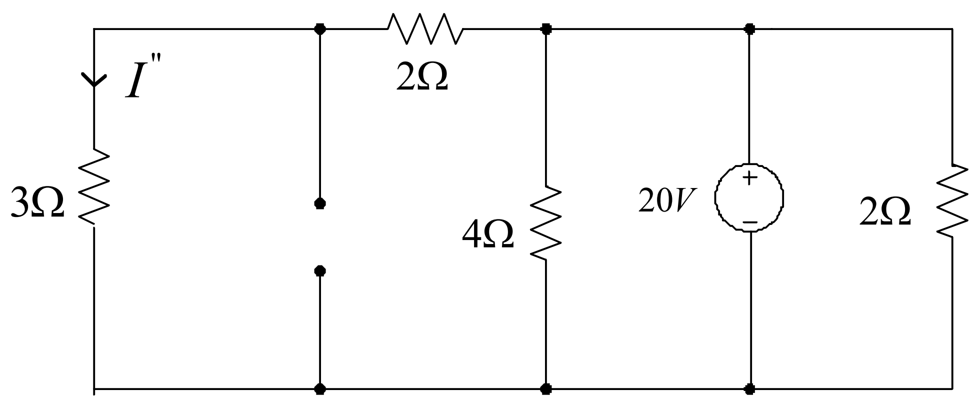
SOLUTION:



The correct answer is *c*.

Use superposition.

$$I^{'} = \left(\frac{2}{2+3}\right)(-10) = -4A$$



$$I'' = \frac{20}{5} = 4A$$
$$I = I' + I''$$
$$I = -4 + 4$$
$$I = 0A$$

5FE-5 What is the open circuit voltage V_{oc} at terminals a and b of the circuit in Fig. 5PFE-5?

a. 8 V
b. 12 V
c. 4 V
d. 10 V

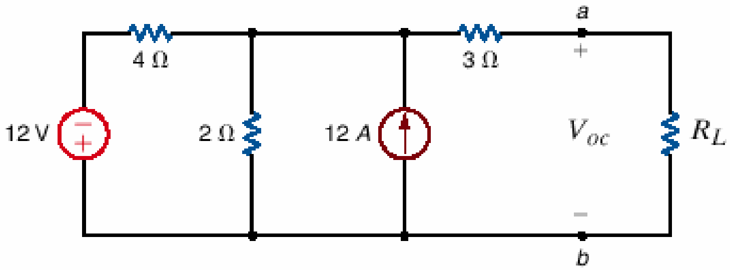
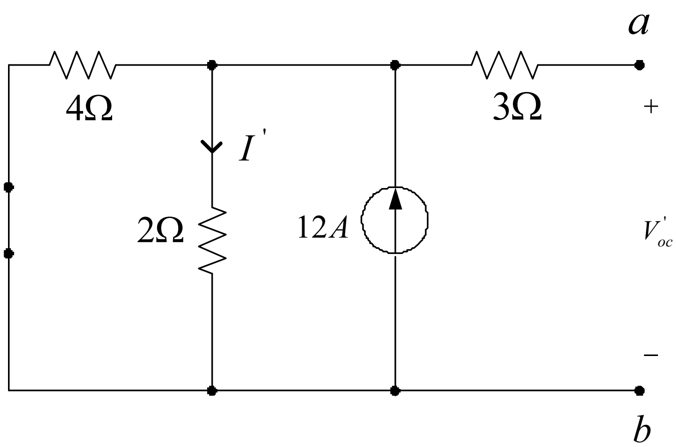


Figure 5PFE-5

SOLUTION:

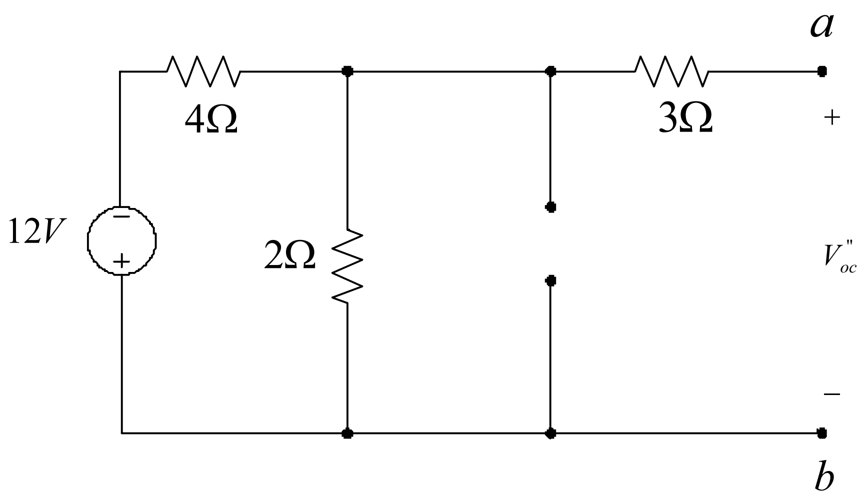
Use superposition.



The correct answer is *b*.

$$I' = \left(\frac{4}{2+4}\right)(12) = 8A$$

$$V'_{oc} = I'(2) = 8(2) = 16V$$



$$V_{oc}^{"} = \left(\frac{2}{2+4}\right)(-12) = -4V$$

$$V_{oc} = 16 - 4 = 12V$$

6.1 A 12-μF capacitor has an accumulated charge of 480 μC. Determine the voltage across the capacitor.

SOLUTION:

$$C = \frac{Q}{V}$$

$$V = \frac{Q}{C}$$

$$V = \frac{480\mu}{12\mu}$$

$$V = 40V$$

6.2 A capacitor has an accumulated charge of 600 μC with 5 V across it. What is the value of capacitance?

SOLUTION:

$$C = \frac{Q}{V}$$

$$C = \frac{600\mu}{5}$$

$$C = 120\,\mu F$$

6.3 A 25-μF capacitor initially charged to −10 V is charged by a constant current of 2.5 μA. Find the voltage across the capacitor after $2\frac{1}{2}$ min.

SOLUTION:

$$V(t) = \frac{1}{C}\int_0^t i(t)\,dt + V(0)$$

$$V(t) = \frac{1}{25\mu}\int_0^{150} 2.5\mu\,dt - 10$$

$$v(t) = \frac{2.5\mu}{25\mu}[150] - 10$$

$$V(t) = 5\text{V}$$

6.4 A capacitor is charged by a constant current of 2 mA and results in a voltage increase of 12 V in a 10-s interval. What is the value of the capacitance?

SOLUTION:

$$V(t_2) - V(t_1) = \frac{1}{C}\int_{t_1}^{t_2} i(t)\,dt$$

$$V(t_2) - V(t_1) = \frac{1}{C}\left[I(t_2 - t_1)\right]$$

$$12 = \frac{I}{C}(10)$$

$$C = \frac{2\times10^{-3}(10)}{12}$$

$$C = 1.67 \text{ mF}$$

6.5 The current in a 100-μF capacitor is shown in Fig. P6.5. Determine the waveform for the voltage across the capacitor if it is initially uncharged.

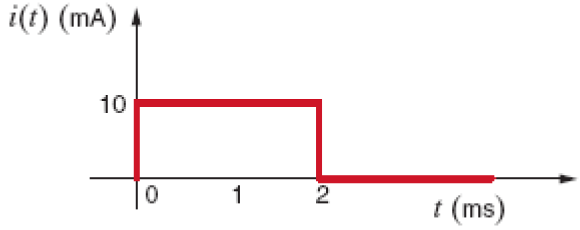


Figure P6.5

SOLUTION:

$t_1 = 2ms$

$$V = \frac{1}{C}\int i\,dt + V_0$$

$t < 0$, $i = 0$, and $V = 0$

$0 \leq t < t$, $i = 10mA$, and

$$V = \frac{1}{100\mu}\int_0^{2m} 10m\,dt$$

$$V = \frac{10m}{100\mu}\Big[t\Big]_0^{2m} = 100t\ V$$

$t \geqslant t_1$

$$V = \frac{1}{C}\int 0\,dt + 100(2m)$$

$$V = 0{\cdot}2\ V$$

$$V(t) = \begin{cases} 0\,\text{V}, & t < 0 \\ 100t\,\text{V}, & 0 \leq t < t_1 \\ 0.2\,\text{V}, & t \geq t_1 \end{cases}$$

6.6 The voltage across a 50-μF capacitor is shown in Fig. P6.6. Determine the current waveform.

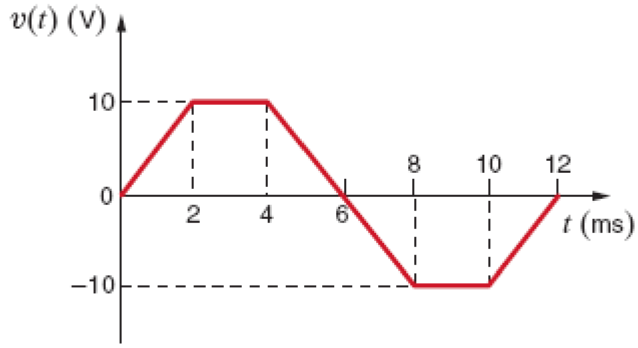


Figure P6.6

SOLUTION:

$$i(t) = C\frac{dv}{dt}$$

$$0 \leq t \leq 2ms$$

$$i(t) = 50\mu[5000]$$

$$i(t) = 250\,mA$$

for $2ms \leq t \leq 4ms$

$$i(t) = 0A$$

for $4ms \leq t \leq 8ms$

$$i(t) = 50\mu[-5000]$$

$$i(t) = -250\,mA$$

for $8ms \leq t \leq 10ms$

$$i(t) = 0A$$

for $10ms \leq t \leq 12ms$

$$i(t) = 50\mu\,[5000]$$

$$i(t) = 250mA$$

for $i(t) = 250mA$

for $t > 12ms$

$$i(t) = 0A$$

$$i(t) \text{ (in mA)} = \begin{cases} 250 & 0 \leq t \leq 2ms \\ 0 & 2ms \leq t \leq 4ms \\ -250 & 4ms \leq t \leq 8ms \\ 0 & 8ms \leq t \leq 10ms \\ 250 & 10ms \leq t \leq 12ms \\ 0 & t > 12ms \end{cases}$$

6.7 Draw the waveform for the current in a 12-μF capacitor when the capacitor voltage is as described in Fig. P6.7.

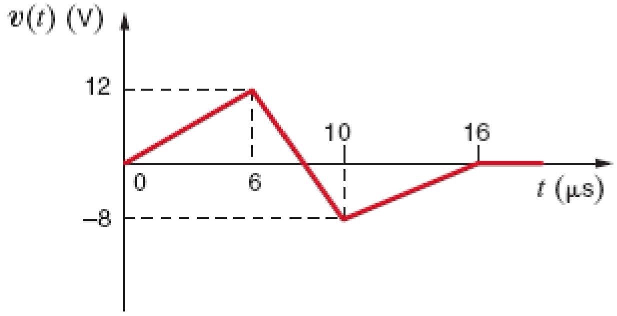


Figure P6.7

SOLUTION:

$$i(t) = C\frac{dV}{dt}$$

for $0 \leq t \leq 6\mu s$

$$i(t) = 12\mu\,[2\times10^6]$$

$$i(t) = 24A$$

for $6\mu s \leq t \leq 10\mu s$

$$i(t) = 12\mu\,[-5\times10^6]$$

$$i(t) = -60A$$

for $10\mu s \leq t \leq 16\mu s$

$$i(t) = 12\mu\,[1.33\times10^6]$$

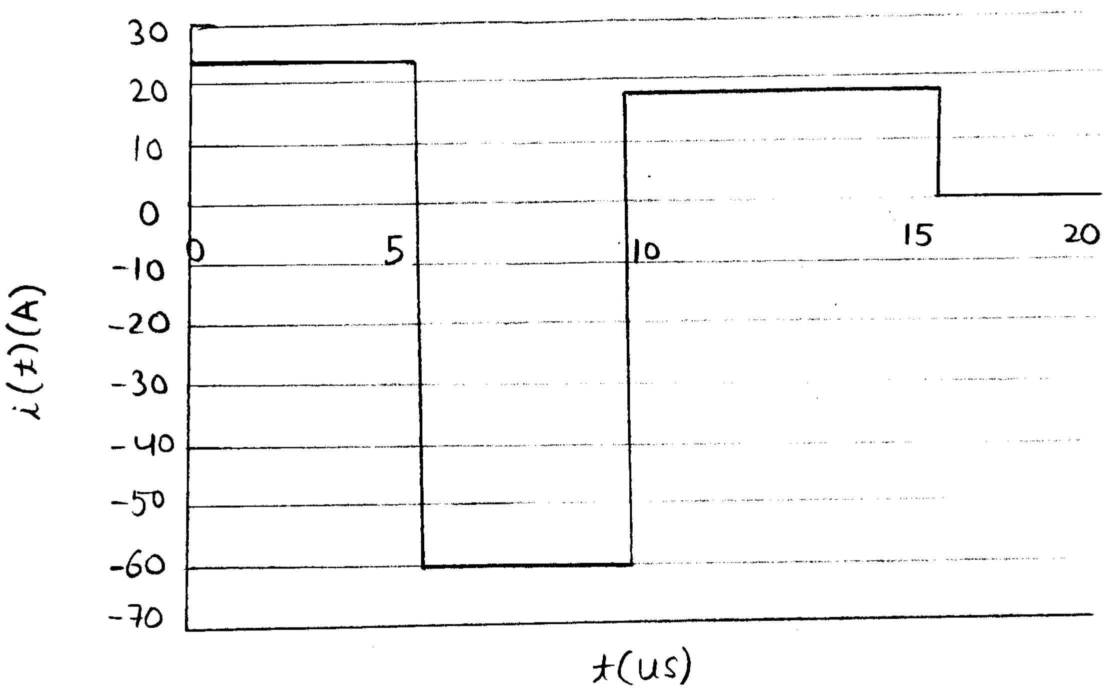
$$i(t) = 16A$$

for $t > 16\mu s$

$$i(t) = 0$$

$$
i(t) = \begin{cases} 24\text{A} & 0 \le t \le 6\,\mu\text{s} \\ -60\text{A} & 6\,\mu\text{s} \le t \le 10\,\mu\text{s} \\ 16\text{ A} & 10\,\mu\text{s} \le t \le 16\,\mu\text{s} \\ 0\text{ A} & t > 16\,\mu\text{s} \end{cases}
$$

$i(t)$ vs. t



6.8 The voltage across a 25-μF capacitor is shown in Fig. P6.8. Determine the current waveform.

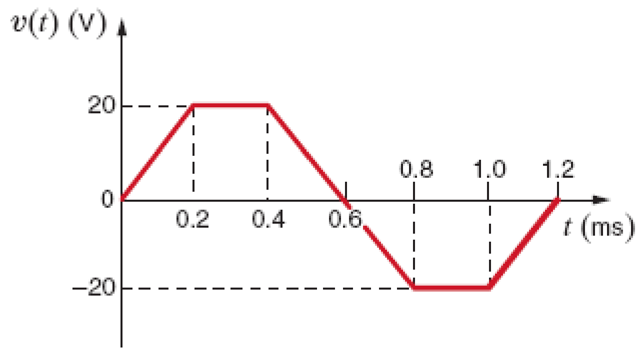


Figure P6.8

SOLUTION:

$t_1 = 0.2\text{ms}$

$t_2 = 0.4\text{ms}$

$t_3 = 0.8\text{ms}$

$t_4 = 1\text{ms}$

$t_5 = 1.2\text{ms}$

$$i = C\frac{dV}{dt}$$

$t < 0$, $V = 0$, and $i = 0$

$0 \le t < t_1$, $V = 10^5 t$ V

$i = 25\mu[10^5] = 2.5$A

$t_1 \le t < t_2$, $V = 20V$, $i = 0$

$t_2 \le t < t_3$, $V = 60 - 10^5 t$ V

$i = 25\mu[-10^5] = -2.5\text{ A}$

$t_3 \leq t < t_4$, $V=0$; $i=0$

$t_4 \leq t < t_5$, $V = -120 \times 10^5 t$

$i = 25\mu[10^5] = 2.5\text{A}$

$$i(t) = \begin{cases} 0 & t < 0 \\ 2.5 & 0 \leq t < 0.2\text{ms} \\ 0 & 0.2\text{ms} \leq t < 0.4\text{ms} \\ -2.5 & 0.4\text{ms} \leq t < 0.8\text{ms} \\ 0 & 0.8\text{ms} \leq t < 1\text{ms} \\ 2.5 & 1\text{ms} \leq t < 1.2\text{ms} \\ 0 & t \geq 1.2\text{ms} \end{cases}$$

6.9 The voltage across a 1-F capacitor is given by the waveform in the Fig. P6.9. Find the waveform for the current in the capacitor.

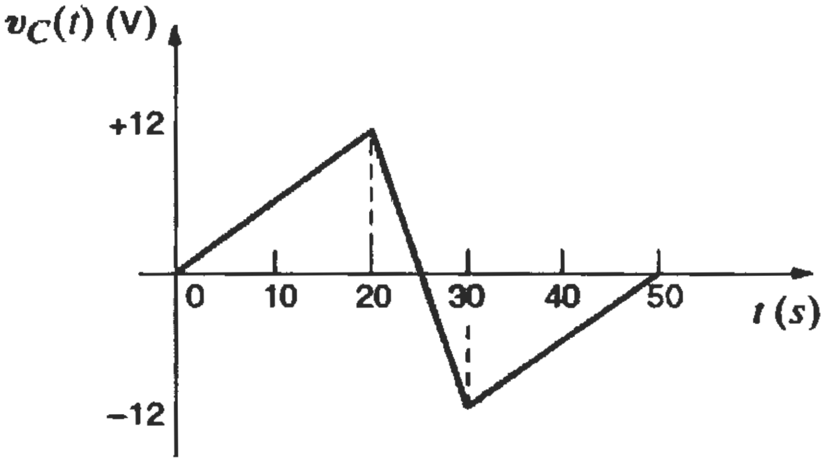


Figure P6.9

Solution: 6.9

$i = C\dfrac{dv}{dt}$, $t_1 = 20s$, $t_2 = 30s$, $t_3 = 50s$

<u>$t<0$</u> $V=0$, $\dfrac{dv}{dt} = 0$, $i = 0$

<u>$0 \leqslant t < t_1$</u> At $t=20s$, $dv = 12V$, $dt = 20s$

$$\frac{dv}{dt} = \frac{12}{20} = 0{\cdot}6 \ V/s \ , \ i = 0{\cdot}6 \ A$$

<u>$t_1 \leqslant t < t_2$</u> At $t = 30s$, $dv = -12 - 12 = -24$ V, $dt = 30 - 20 = 10s$

$$\frac{dv}{dt} = \frac{-24}{10} = -2{\cdot}4 \ V/s \ , \ i = -2{\cdot}4 \ A$$

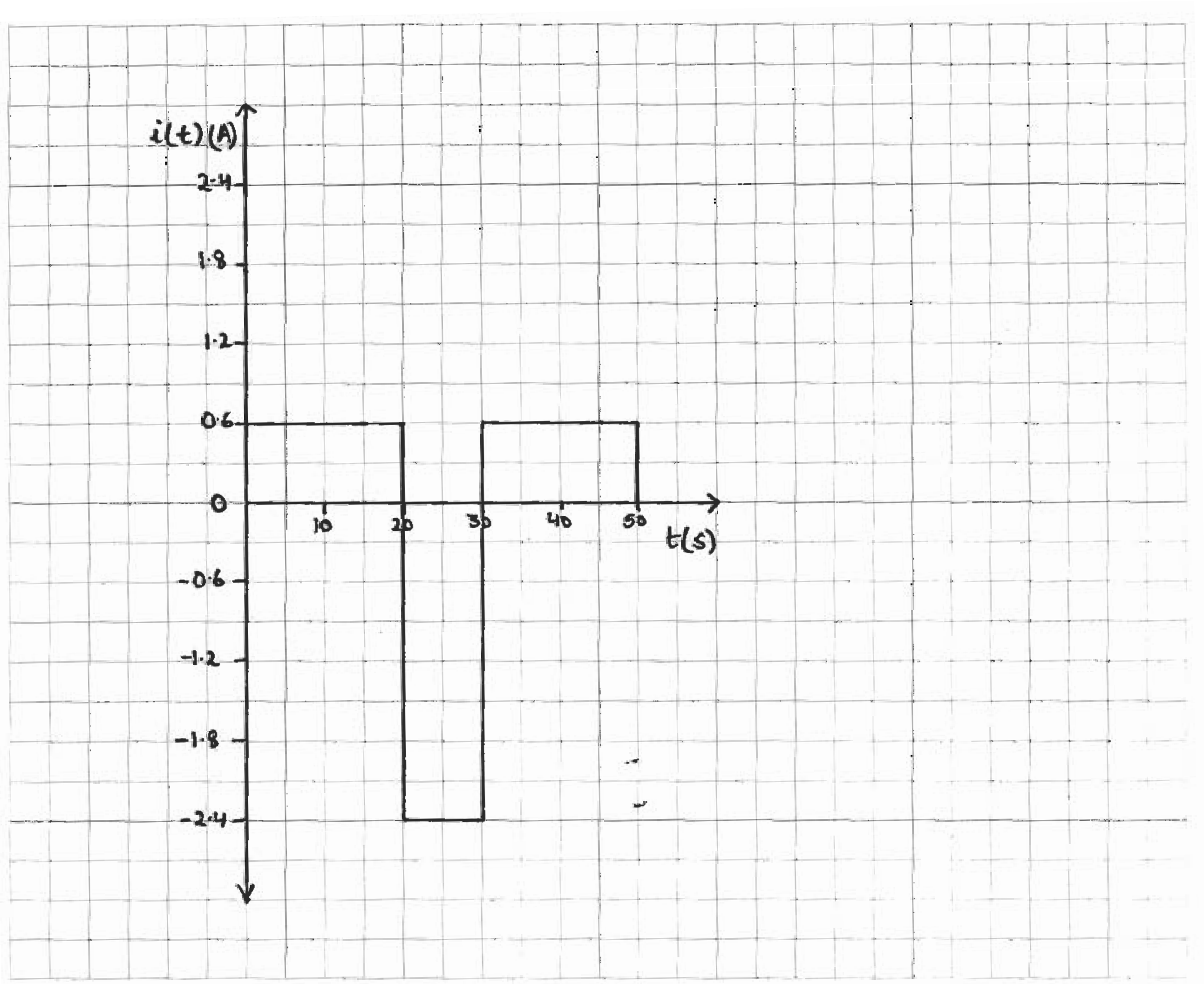
$\underline{t_2 \leq t \leq t_3}$ At $t = 50s$, $dv = -12V$, $dt = 20s$

$$\frac{dv}{dt} = \frac{-12}{20} = 0.6 \text{ V/s}, \quad i = 0.6 \text{ A}$$

$\underline{t \geq t_3}$ $V = 0$, $\frac{dv}{dt} = 0$, $i = 0$

$$i(t) = \begin{cases} 0\text{ A} & t < 0 \\ 0.6\text{ A} & 0 \leq t < 20s \\ -2.4\text{ A} & 20s \leq t < 30s \\ 0.6\text{ A} & 30s \leq t < 50s \\ 0\text{ A} & t \geq 50s \end{cases}$$

Therefore current waveform is



6.10 The Voltage across a 1-μF capacitor is given by the waveform in the Fig. P6.10. Compute the current waveform.

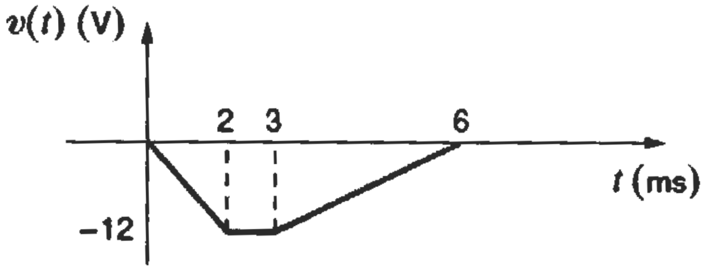


Figure P6.10

Solution: 6.10

$t_1 = 2ms$, $t_2 = 3ms$, $t_3 = 6ms$ $\quad i = C\dfrac{dv}{dt}$

$t < 0$, $V = 0$, $\dfrac{dv}{dt} = 0$, $i = 0$

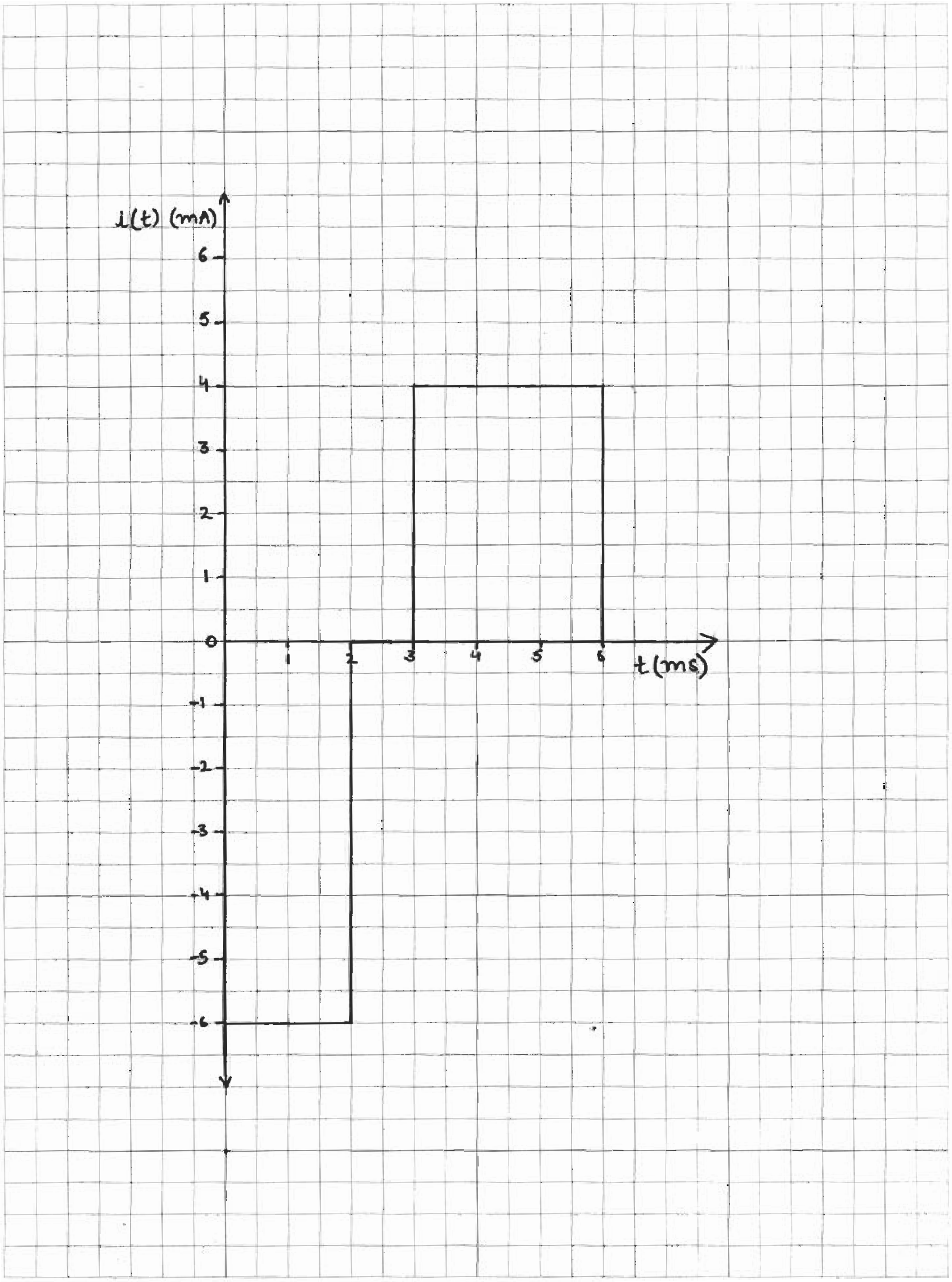
$0 \leqslant t < t_1$, $\dfrac{dv}{dt} = \dfrac{-12}{2} = -6 \text{ V/ms}$, $i = -6 \text{ mA}$

$t_1 \leqslant t < t_2$, $\dfrac{dv}{dt} = 0$, $i = 0 \text{ mA}$

$t_2 \leqslant t < t_3$, $\dfrac{dv}{dt} = \dfrac{12}{3} = 4 \text{ V/ms}$, $i = 4 \text{ mA}$

$t \geqslant t_3$, $\dfrac{dv}{dt} = 0$, $i = 0$

$$\therefore\ i(t) = \begin{cases} 0 \text{ mA} & t < 0 \text{ ms} \\ -6 \text{ mA} & 0 \text{ ms} \leqslant t < 2 \text{ ms} \\ 0 \text{ mA} & 2 \text{ ms} \leqslant t < 3 \text{ ms} \\ 4 \text{ mA} & 3 \text{ ms} \leqslant t < 6 \text{ ms} \\ 0 \text{ mA} & t \geqslant 6 \text{ ms} \end{cases}$$


i(t) (mA)
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
1
2
3
4
5
6
t(ms)

6.11 Draw the waveform for the current in a 24-μF capacitor when the capacitor voltage is as described in Fig. P6.11.

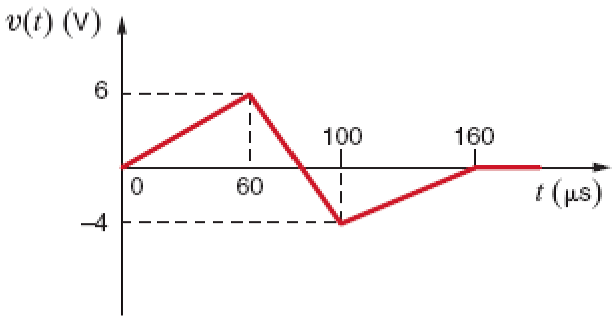


Figure P6.11

SOLUTION:

$t < 0$, $V = 0$, $i = 0$

$0 \leq t < 60\mu s$, $V = 10^5 t$ V

$$i = C\frac{dV}{dt}$$

$$i = (24\mu)(10^5)$$

$$i = 2.4A$$

$60\mu s \leq t < 100\mu s$, $V = 21 - 2.5 \times 10^5 t$ V

$$i = (24\mu)(-2.5 \times 10^5)$$

$$i = -6A$$

$100\mu s \leq t < 160\mu s$, $V = \frac{-32}{3} + \frac{10^6}{15} t$ V

$$i = 24\mu\left[\frac{10^6}{15}\right]$$

$$i = 1.6A$$

$t \geq 160\mu s$, $V=0$, $i=0$

$$i(t) = \begin{cases} 0 & t < 0 \\ 2.4A & 0 \leq t < 60\mu s \\ -2.4A & 60\mu s \leq t < 100\mu s \\ 1.6A & 100\mu s \leq t < 160\mu s \\ 0 & t \geq 160\mu s \end{cases}$$

6.12 The voltage across a 10-μF capacitor is given by the waveform in Fig. P6.12. Plot the waveform for the capacitor current.

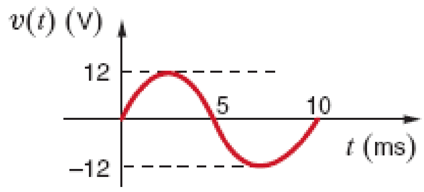


Figure P6.12

SOLUTION:

$$i = C\frac{dv}{dt}$$

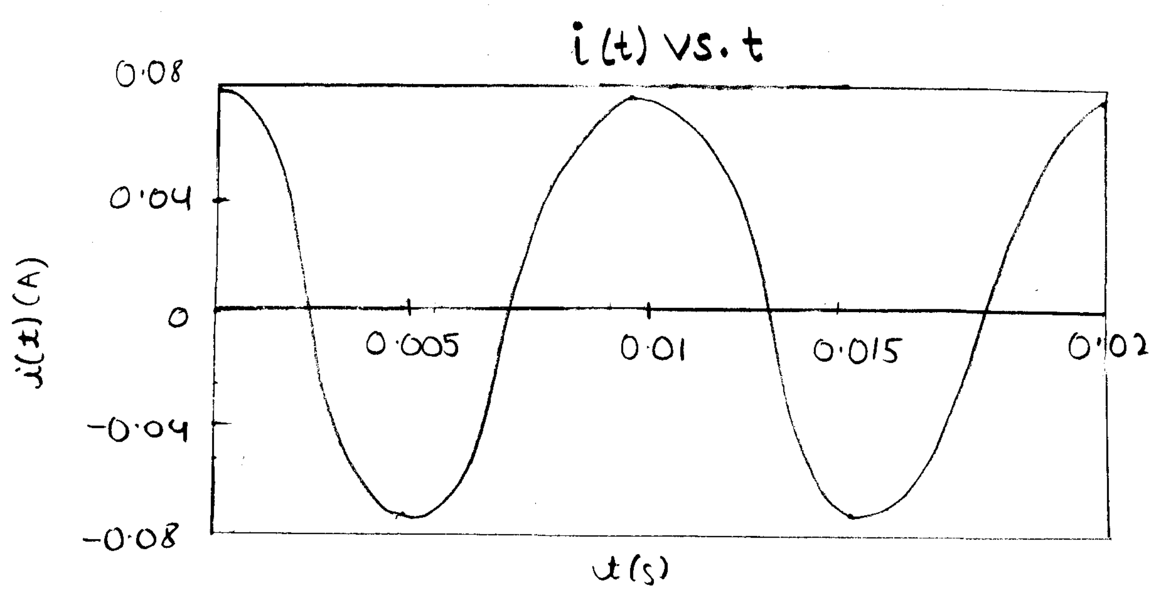
$$v(t) = 12\sin\omega t \quad , \quad T = 10ms$$

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{10m}$$

$$\omega = 200\pi \text{ rad/s}$$

$$i(t) = (10\mu)(12)(\omega)\cos\omega t$$

$$i(t) = 75.4\cos\omega t \text{ mA}$$



6.13 The waveform for the current in a 26-μF capacitor is shown in the Fig. P6.13. Determine the waveform for the capacitor voltage.

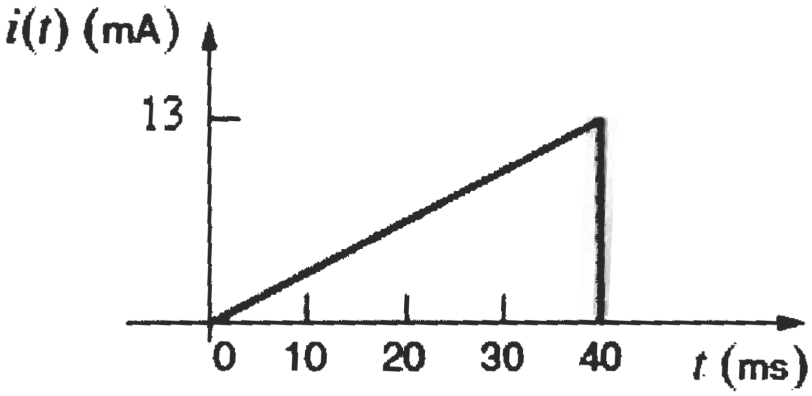


Figure P6.13

Solution: 6.13

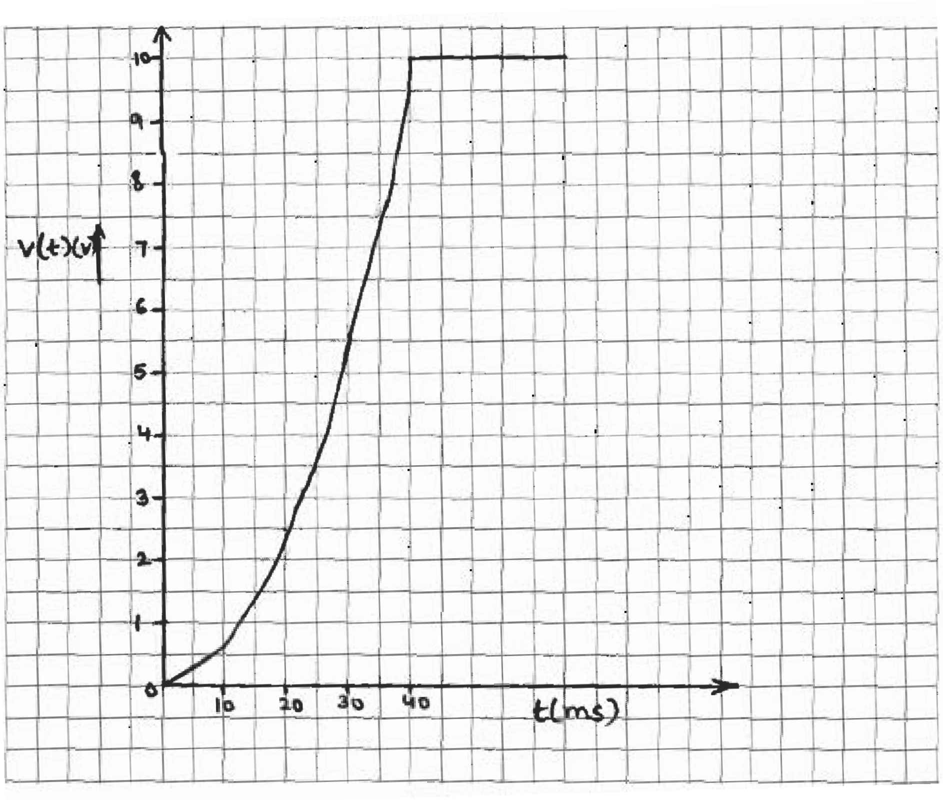
$t_1 = 40\text{ms}$ $\quad\quad V = \frac{1}{C}\int i\,dt + V_0$

$t < 0,\ i(t) = 0,\ V = 0$

$0 \leqslant t < t_1,\ i(t) = \frac{13}{40}t = 0.325t,\ V = 6250t^2\ \text{V}$

$t \geqslant t_1,\ i(t) = 0,\ V = 6250\ (40\times10^{-3})^2 + 0 = 10\text{V}$

$$\therefore\ v(t) = \begin{cases} 0\text{V} & t < 0\text{ms} \\ 6250t^2\ \text{V} & 0 \leqslant t < 40\text{ ms} \\ 10\text{ V} & t \geqslant 40\text{ms} \end{cases}$$


v(t)(v)
10
9
8
7
6
5
4
3
2
1
0
10
20
30
40
t(ms)

6.14 The waveform for the current in a 50-μF initially uncharged capacitor is shown in the Fig. P6.14. Determine the waveform for the capacitor's voltage.

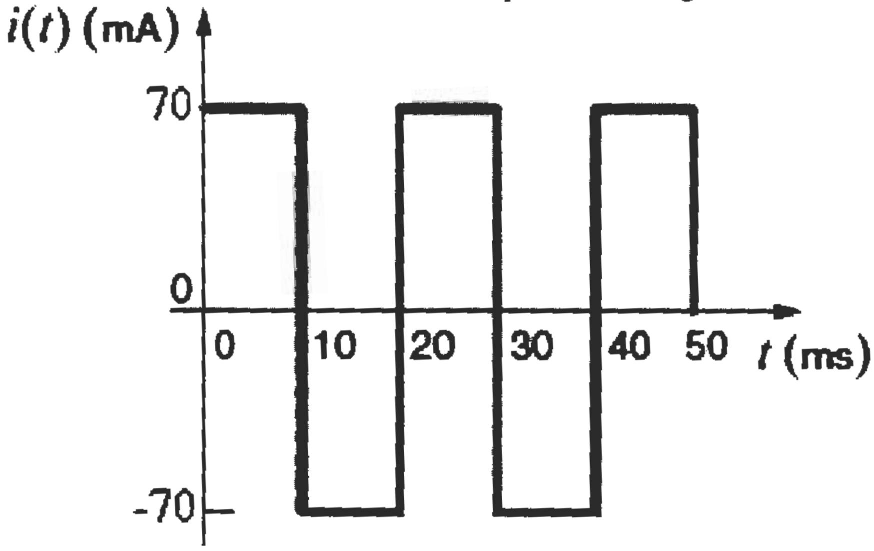


Figure P6.14

Solution: 6.14

$$v(t) = \frac{1}{C}\int i\,dt$$

For $t < 0$, $v(t) = 0$

For $0 \leq t < 10$ ms

$$v(t) = \frac{1}{50\times10^{-6}}\int_0^t (70\times10^{-3})\,dt$$

$$= 1400t \text{ V}$$

For $10 \le t < 20\text{ms}$

$$v(t) = V_0 + \frac{1}{C}\int_{10}^{t} i(t)\,dt$$

$$= 14 + \frac{1}{50\times10^{-6}}(-70\times10^{-3})\,t - \frac{1}{50\times10^{-6}}(-70\times10^{-3})\times10\times10^{-3}$$

$$= 28 - 1400t \text{ V}$$

For $20 \le t < 30\text{ ms}$

$$v(t) = 28 + 1400t - 56$$

$$= -28 + 1400t \text{ V}$$

For $30 \le t < 40\text{ ms}$

$$v(t) = -28 + 42 + 42 - 1400t \text{ V}$$

$$= 56 - 1400t \text{ V}$$

For $40 \le t < 50\text{ ms}$

$$v(t) = 56 - 56 - 56 + 1400t$$

$$= -56 + 1400t \text{ V}$$

For $t > 50\text{ ms}$

$$v(t) = 0 \text{ V}$$

$$v(t) = \begin{cases} 0\text{ V} & t < 0 \\ 1400t\text{ V} & 0 \le t < 10\text{ms} \\ 28 - 1400t\text{ V} & 10 \le t < 20\text{ms} \\ -28 + 1400t\text{ V} & 20 \le t < 30\text{ ms} \\ 56 - 1400t\text{ V} & 30 \le t < 40\text{ ms} \\ -56 + 1400t\text{ V} & 40 \le t < 50\text{ ms} \\ 0\text{ V} & t > 50\text{ ms} \end{cases}$$

6.15 The waveform for the current flowing through the 10-µF capacitor in Fig. P6.15a is shown in Fig. P6.15b. If $v_c(t = 0) = 1\,V$, determine $v_c(t)$ at $t = 1$ ms, 3 ms, 4 ms, and 5 ms.

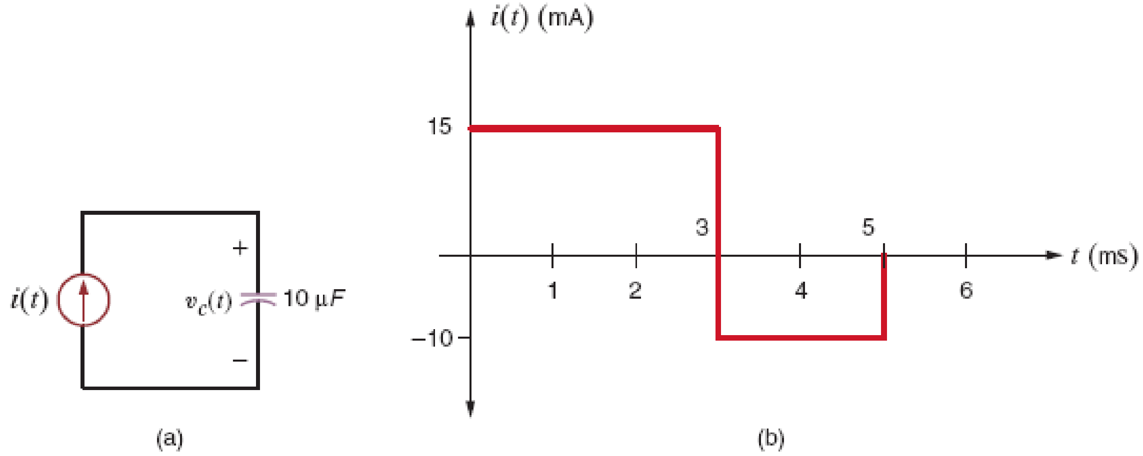


Figure P6.15

SOLUTION:

$$V_C(0) = 1\,V$$

$$V_C(t) = V_C(t_0) + \frac{1}{C}\int_{t_0}^{t} i(t)\,dt$$

$$V_C(1ms) = V_C(0) + \frac{1}{C}\int_0^{1m} (15m)\,dt$$

$$V_C(1ms) = 1 + \frac{1}{10\mu}\int_0^{1m} (15m)\,dt$$

$$V_C(1ms) = 1 + 100\times10^3(15\times10^{-3})[t]_0^{1m}$$

$$V_C(1ms) = 1 + 1500t$$

$$V_C(1ms) = 1 + 1500(1m)$$

$$V_C(1ms) = 2.5\,V$$

$$V_C(3ms) = V_C(1ms) + \frac{1}{10\mu}\int_{1m}^{t} 15m\,dt$$

$$V_C(3ms) = 2.5 + 100\times10^3(15\times10^{-3})\ [t]_{1m}^{t}$$

$$\dot{V}_C(3ms) = 2.5 + 1500\ [t - 1m]$$

$$V_C(3ms) = 2.5 + 1500\ [3m - 1m]$$

$$V_C(3ms) = 5.5\ V$$

$$V_C(4ms) = V_C(3m) + \frac{1}{10\mu}\int_{3m}^{t} -10m\,dt$$

$$V_C(4ms) = 5.5\ \times100\times10^3\ (-10\times10^{-3})[t]_{3m}^{t}$$

$$V_C(4ms) = 5.5 - 1000[t - 3m]$$

$$V_C(4ms) = 5.5 - 1000[4m - 3m].$$

$$V_C(4ms) = 4.5\ V$$

$$V_C(5ms) = V_C(4m) + \frac{1}{10\mu}\int_{4m}^{t} -10m\,dt$$

$$V_C(5ms) = 4.5 + 100\times10^3(-10\times10^{-3})[t]_{4m}^{t}$$

$$V_c(5ms) = 4.5 - 1000[t - 4m]$$
$$= 4.5 - 1000[5m - 4m]$$

$$V_c(5ms) = 3.5\ V$$

6.16 If $v_c(t = 2\text{ s}) = 10$ V in the circuit in Fig. P6.16, find the energy stored in the capacitor and the power supplied by the source at $t = 6$ s.

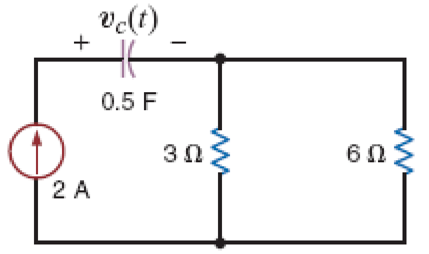
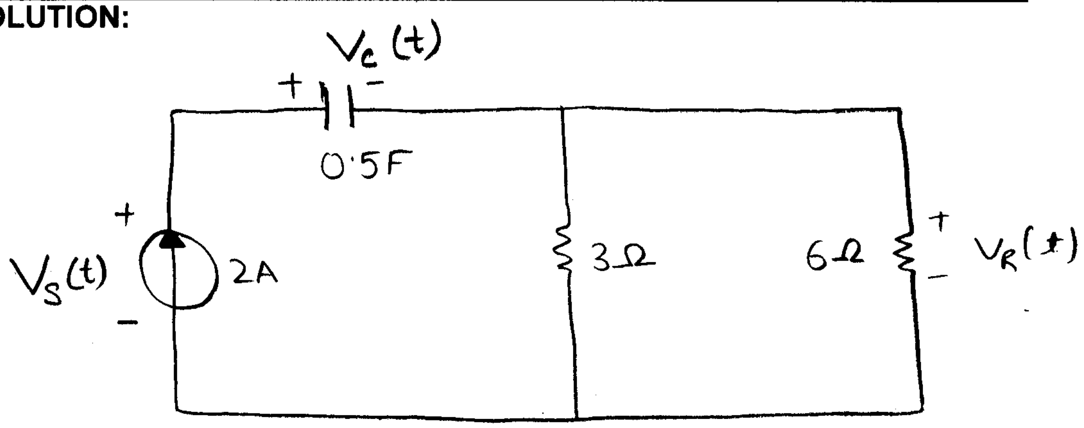


Figure P6.16

SOLUTION:



$$V_c(t_2) = \frac{1}{C}\int_{t_1}^{t_2} i_c(t)\,dt + V_c(2)$$

$$V_c(t_2) = 2\int_{2}^{6} 2\,dt + 10$$

$$V_c(t_2) = 2\left[2t\right]_2^6 + 10$$

$$V_c(t_2) = 2\left[2(6) - 2(2)\right] + 10$$

$$V_c(t_2) = 26V$$

$$W_C(t_2) = \frac{1}{2}C\left[v_C(t_2)\right]^2$$

$$W_C(t_2) = \frac{1}{2}\left(\frac{1}{2}\right)\left[26\right]^2$$

$$W_C(t_2) = 169\text{J}$$

$$V_R(t_2) = i(t_2)\left[\frac{3(6)}{3+6}\right] = 2\left[\frac{18}{9}\right]$$

$$V_R(t_2) = 4\text{V}$$

$$V_S(t_2) = V_C(t_2) + V_R(t_2)$$

$$V_S(t_2) = 26+4$$

$$V_S(t_2) = 30\text{V}$$

$$P_S(t_2) = V_S(t_2)\, i_S(t_2)$$

$$P_S(t_2) = 30(2)$$

$$P_S(t_2) = 60\text{W}$$

6.17 The current in an inductor changes from 0 to 50 mA in 2 ms and induces a voltage of 50 mV. What is the value of the inductor?

Solution: 6.17

$$V = L\frac{di}{dt} \Rightarrow V = L\frac{\Delta i}{\Delta t}$$

$\Delta i = 50\text{ mA}$, $\Delta t = 2\text{ms}$, $V = 50\text{ mV}$

$$L = V\frac{\Delta t}{\Delta i}$$

$$\boxed{L = 2\text{ mH}}$$

6.18 The current in a 100-mH inductor is $i(t) = 2 \sin 377t\ A$. Find (a) the voltage across the inductor and (b) the expression for the energy stored in the element.

SOLUTION:

(a) $$V(t) = L\frac{di(t)}{dt}$$

$$V(t) = 0.1(2)(377) \cos 377t$$

$$V(t) = 75.4 \cos 377t\ V$$

(b) $$w(t) = \frac{1}{2} L i^2(t)$$

$$wt = \frac{1}{2}(0.1)\left[2 \sin 377t\right]^2$$

$$wt = 0.2 \sin^2 377t\ J$$

6.19 If the current $i(t) = 2.0t$ A flows through a 4-H inductor, find the energy stored at $t = 3s$.

Solution: 6.19

$$w(t) = \frac{1}{2} L \left[i(t)\right]^2$$

$$w(3) = \frac{1}{2} \times 4 \times [2 \times 3]^2$$

$$= 72 \text{ J}$$

$$\boxed{w(3) = 72 \text{ J}}$$

6.20 The current in a 25-mH inductor is given by the expressions

$$i(t) = 0 \qquad t < 0$$
$$i(t) = 10(1 - e^{-t}t)\text{ mA} \qquad t > 0$$

Find (a) the voltage across the inductor and (b) the expression for the energy stored in it.

SOLUTION:

Assumption: $i(t) = 10(1 - e^{-t})$

(a) $V(t) = L\dfrac{di(t)}{dt}$

$$\frac{di(t)}{dt} = \begin{cases} 0 & , t < 0 \\ 10e^{-t} & , t > 0 \end{cases}$$

$$V(t) = \begin{cases} 0 & , t < 0 \\ 250e^{-t}\ \mu V & , t > 0 \end{cases}$$

(b) $w(t) = \dfrac{1}{2}Li^2(t)$

$$w(t) = \begin{cases} 0J & , t < 0 \\ 1.25\,(1-e^{-t})^2\ \mu J & , t > 0 \end{cases}$$

6.21 The current in a 25-mH inductor is given by the expressions

$$i(t) = 0 \qquad t < 0$$

$$i(t) = 14(1 - e^{-t})\text{mA} \qquad t > 0$$

Find

(a) the voltage across the inductor and

(b) the energy stored in it after 1 s.

Solution: 6.21

(a) $V = L \dfrac{di}{dt}$

$$V = \begin{cases} 0\text{ V} & t < 0 \\ 350\, e^{-t}\ \mu\text{V} & t > 0 \end{cases}$$

(b) $w(t) = \dfrac{1}{2} L\, i^2(t)$

$$\boxed{w(1) = 0.979\ \mu\text{J}}$$

6.22 The current in 50-mH inductor is specified as follows.

$$i(t) = 0 \qquad t < 0$$
$$i(t) = 2te^{-4t}\text{ A} \qquad t > 0$$

Find (a) the voltage across the inductor, (b) the time at which the current is a maximum, and (c) the time at which the voltage is a minimum.

SOLUTION:

$$i(t) = 0\text{ A} \qquad t < 0$$
$$i(t) = 2te^{-4t}\text{ A}, \quad t > 0$$

(a) $$V_L(t) = L\frac{di(t)}{dt}$$

$$V_L(t) = 50m\left[2t(-4)e^{-4t} + e^{-4t}(2)\right]$$

$$V_L(t) = -0.4te^{-4t} + 0.1e^{-4t}$$

$$V_L(t) = 0.1e^{-4t}(1-4t)\text{ V}$$

$$V_L(t) = 0\text{ V}, \quad t < 0$$

$$V_L(t) = 0.1e^{-4t}(1-4t)\text{ V}, \quad t > 0$$

(b) The time when $i(t)$ is maximum is found when

$$\frac{di(t)}{dt} = 0$$

$$\frac{di(t)}{dt} = 2e^{-4t} - 8te^{-4t}$$

$$2e^{-4t} - 8te^{-4t} = 0$$

$$8te^{-4t} = 2e^{-4t}$$

$$t = 0.25\text{ s}$$

(c) $V_L(t) = 0.1e^{-4t}(1-4t)\text{ V}$

$$V_L(t) = 0.1e^{-4t} - 0.4te^{-4t}$$

$$\frac{dV_L(t)}{dt} = -4(0.1)e^{-4t} - 0.4(-4)te^{-4t} - 0.4e^{-4t}$$

$$-0.4e^{-4t} + 1.6te^{-4t} - 0.4e^{-4t} = \frac{dV_L(t)}{dt}$$

$$-0.8e^{-4t} + 1.6te^{-4t} = \frac{dV_L}{dt}(t)$$

$$= 0$$

$$0.8e^{-4t} = 1.6te^{-4t}$$

or $t = 1/2$

6.23 The voltage across a 4-H inductor is given by the waveform shown in the Fig. P6.23. Find the waveform for the current in the inductor.

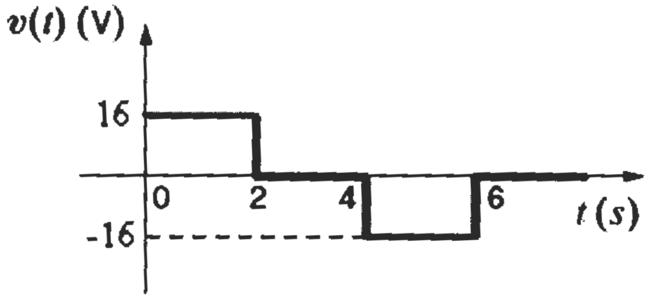


Figure P6.23

Solution: 6.23

$$i(t) = \frac{1}{L}\int v(t)\,dt$$

$L = 4\,H$

For $t < 0$, $i(t) = 0$ since $v(t) = 0$

For $0 \le t < 2s$

$$i(t) = \frac{1}{4}\int_0^t 16\,dt = 4t \text{ A}$$

For $2 \le t < 4s$

$$i(t) = i_0 + \frac{1}{4}\int_2^4 v(t)\,dt$$

$= (4 \times 2)\text{ A} + 0$ ($\because$ $v(t) = 0$ in the interval)

$= 8\text{ A}$

For $4 \le t < 6s$

$$i(t) = 8 + \frac{1}{4}\int_4^t (-16)\,dt$$

$$= 8 - 4t - (-4) \times 4$$

$$= 24 - 4t \quad A$$

For $t > 6\,s$

$$i(t) = 0 \; A$$

$$i(t) = \begin{cases} 0\,A & t < 0s \\ 4t\,A & 0 \leq t < 2s \\ 8\,A & 2s \leq t < 4s \\ 24 - 4t\,A & 4s \leq t < 6s \\ 0\,A & t > 6s \end{cases}$$

6.24 The voltage across a 4-H inductor is given by the waveform shown in Fig. P6.24. Find the waveform for the current in the inductor. $v(t) = 0, t < 0$.

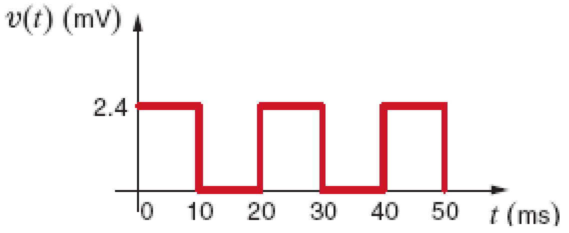


Figure P6.24

SOLUTION:

$$i(t) = \frac{1}{L}\int v(t)\,dt$$

v(t) is constant across the time spans, and i(t) can be written as:

$$i(t) = \frac{V}{L}t + I_0$$

for $t < 0$, $i(t) = 0$

for $0 \leq t \leq 10\text{ms}$

$$i(t) = \frac{2.4m}{4}t$$

$$i(t) = 600t\ \mu A$$

for $10\text{ms} \leq t \leq 20\text{ms}$

$$i(t) = 0 + (600)(10m)$$

$$i(t) = 6\ \mu A$$

for $20ms \leq t \leq 30ms$

$$i(t) = \frac{2.4m}{4} t - 6 = 600t - 6 \ \mu A$$

for $30ms \leq t \leq 40ms$

$$i(t) = 12 \mu A$$

for $40ms \leq t \leq 50ms$

$$i(t) = -12 + 600t \ \mu A$$

for $t \geq 50ms$

$$i(t) = 18 \mu A$$

$$i(t) = \begin{cases} 0 & t < 0 \\ 600t \ \mu A & 0 \leq t \leq 10ms \\ 6 \mu A & 10ms \leq t \leq 20ms \\ -6 + 600t \ \mu A & 20ms \leq t \leq 30ms \\ 12 \mu A & 30ms \leq t \leq 40ms \\ -12 + 600t \ \mu A & 40ms \leq t \leq 50ms \\ 18 \mu A & t \geq 50ms \end{cases}$$

6.25 The voltage across a 10-mH inductor is shown in Fig. P6.25. Determine the waveform for the inductor current.

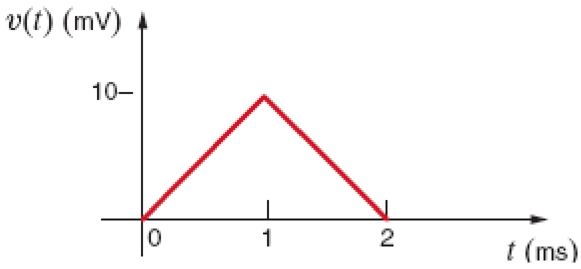


Figure P6.25

SOLUTION:

For $0 \leq t \leq 1\text{ms}$

$$V_L(t) = 10t\text{ mV}$$

$$i_L(t) = \frac{1}{L}\int V_L(t)\,dt$$

$$i_L(t) = 100\int 10t\,dt$$

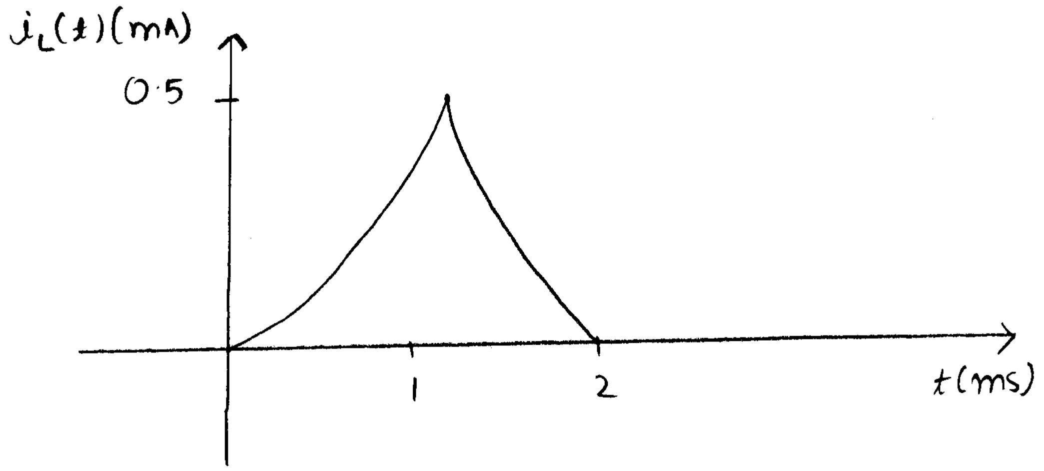
$$i_L(t) = 500\,t^2\text{ mA}$$

for $1\text{ms} \leq t \leq 2\text{ms}$

$$V_L(t) = -10t + 20$$

$$i_L(t) = 100\int(-10t + 20)\,dt$$

$$i_L(t) = -500t^2 + 2000t\text{ mA}$$


i_L(t)(mA)
0.5
1
2
t(ms)

6.26 The current in a 10-mH inductor is shown in Fig. P6.26. Determine the waveform for the voltage across the inductor.

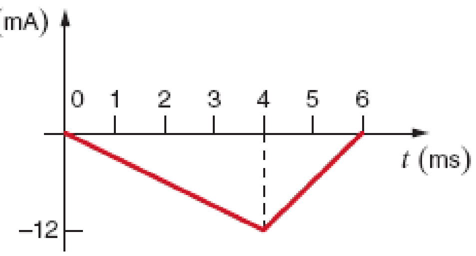


Figure P6.26

SOLUTION:

$$V(t) = L\frac{di(t)}{dt}$$

for $t < 0$, $V(t) = 0$

for $0 < t \leq 4ms$

$$V(t) = 10m\left[\frac{-12m}{4m}\right] = -30mV$$

for $4ms < t \leq 6ms$

$$V(t) = 10m\left[\frac{12m}{2m}\right] = 60mV$$

for $t > 6ms$

$V(t) = 0$

$$Vt = \begin{cases} 0 & t < 0 \\ -30mV & 0 < t \leq 4ms \\ 60mV & 4ms < t \leq 6ms \\ 0 & t > 6ms \end{cases}$$

6.27 The current in a 50-mH inductor is given in the Fig. P6.27. Find the inductor voltage.

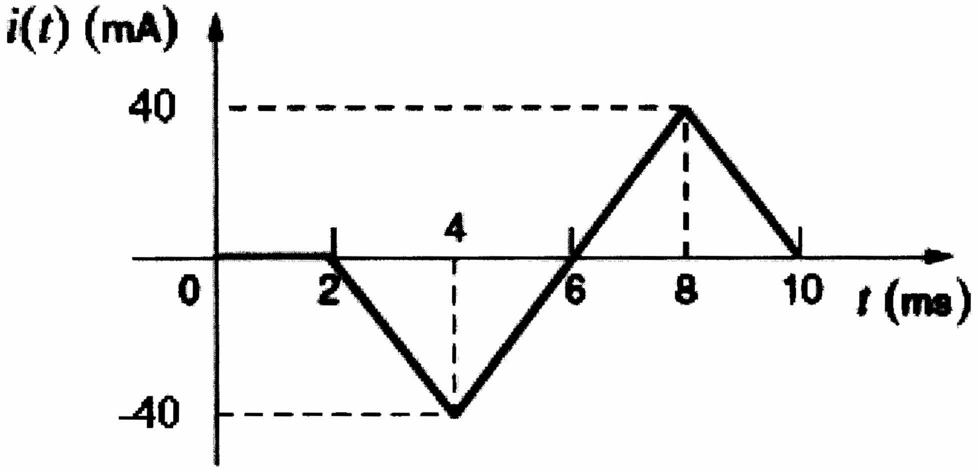


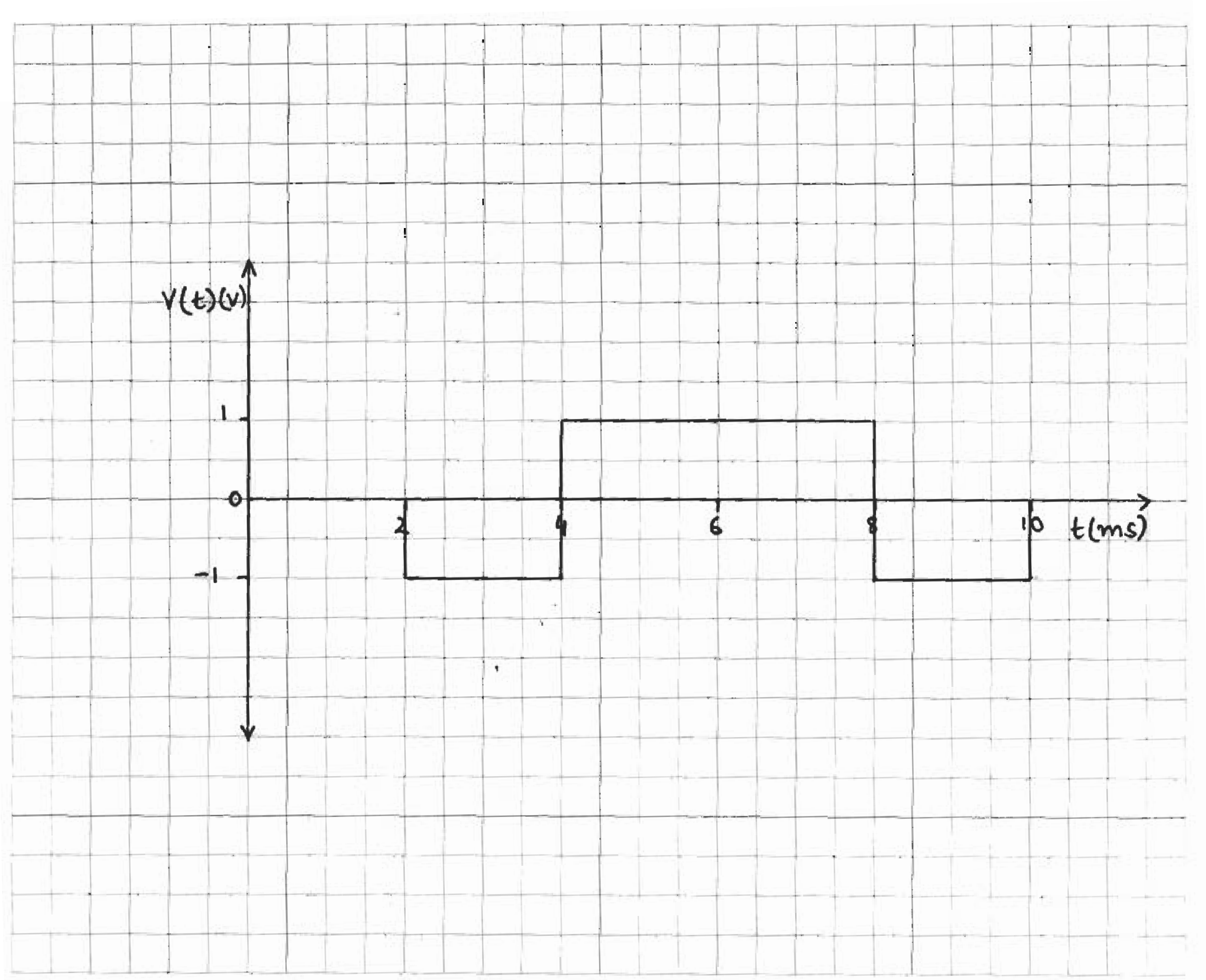
Figure P6.27

Solution: 6·27

$$V = L\frac{di}{dt}$$

$$\frac{di}{dt} = \begin{cases} 0 & 0 \leq t < 2 \\ -20\ A/s & 2 \leq t < 4 \\ 20\ A/s & 4 \leq t < 8 \\ -20\ A/s & 8 \leq t < 10 \end{cases}$$

$$V = \begin{cases} 0 & 0 \leq t < 2 \\ -1V & 2 \leq t < 4 \\ 1V & 4 \leq t < 8 \\ -1V & 8 \leq t < 10 \end{cases}$$



V(t)(V)
1
0
-1
2
4
6
8
10
t(ms)

6.28 The current in a 70-mH inductor is shown in the Fig. P6.28. Find the voltage across the inductor.

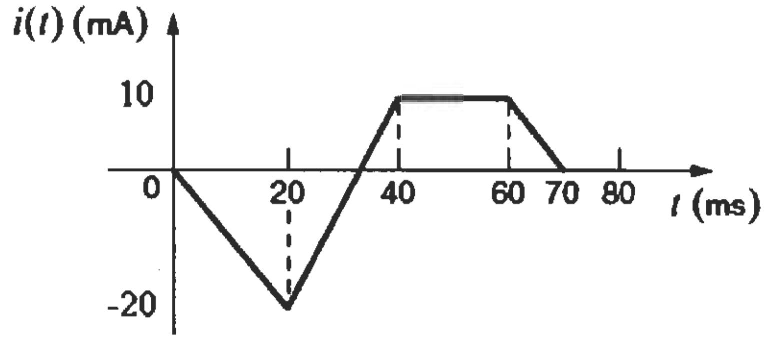


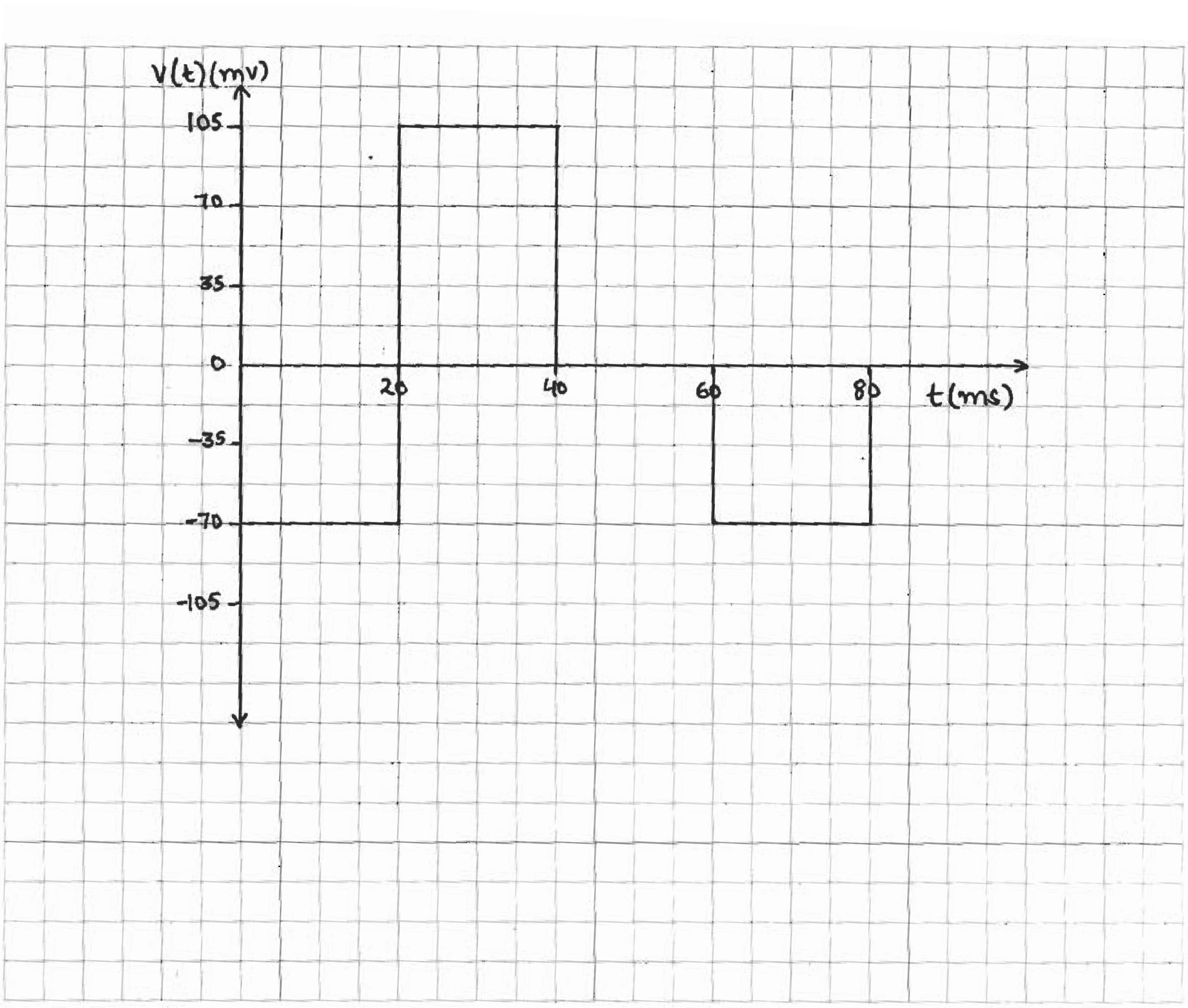
Figure P6.28

Solution: 6·28

$$V = L\frac{di}{dt}$$

$$\frac{di}{dt} = \begin{cases} 0 & t < 0 \\ -1 \text{ A/s} & 0 \leq t < 20 \\ 1{\cdot}5 \text{ A/s} & 20 \leq t < 40 \\ 0 \text{ A/s} & 40 \leq t < 60 \\ -1 \text{ A/s} & 60 \leq t < 70 \end{cases}$$

$$V = \begin{cases} 0 \text{ mv} & t \leq 0 \\ -70 \text{ mv} & 0\text{ms} \leq t < 20\text{ ms} \\ 105 \text{ mv} & 20\text{ms} \leq t < 40\text{ms} \\ 0 \text{ mv} & 40\text{ ms} \leq t < 60\text{ ms} \\ -70 \text{ mv} & 60\text{ ms} \leq t < 70\text{ ms} \\ 0 \text{ mv} & t > 70\text{ms} \end{cases}$$


v(t)(mv)
105
70
35
0
-35
-70
-105
20
40
60
80
t(ms)

6.29 Draw the waveform for the voltage across a 24-mH inductor when the inductor current is given by the waveform shown in Fig. P6.29.

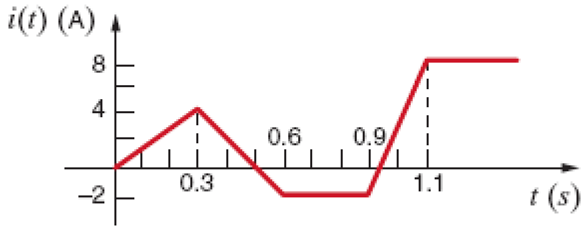


Figure P6.29

SOLUTION:

$$V(t) = L\frac{di(t)}{dt}$$

for $t \leq 0$, $V(t) = 0$

for $0 \leq t \leq 0.3s$

$$V(t) = 24m\left[\frac{40}{3}\right]$$

$$V(t) = 320mV$$

for $0.3s < t \leq 0.6s$

$$V(t) = 24m[-20]$$

$$V(t) = -480mV$$

for $0.6s < t \leq 0.9s$

$$V(t) = 0$$

for $0.9\,s < t \leq 1.1\,s$

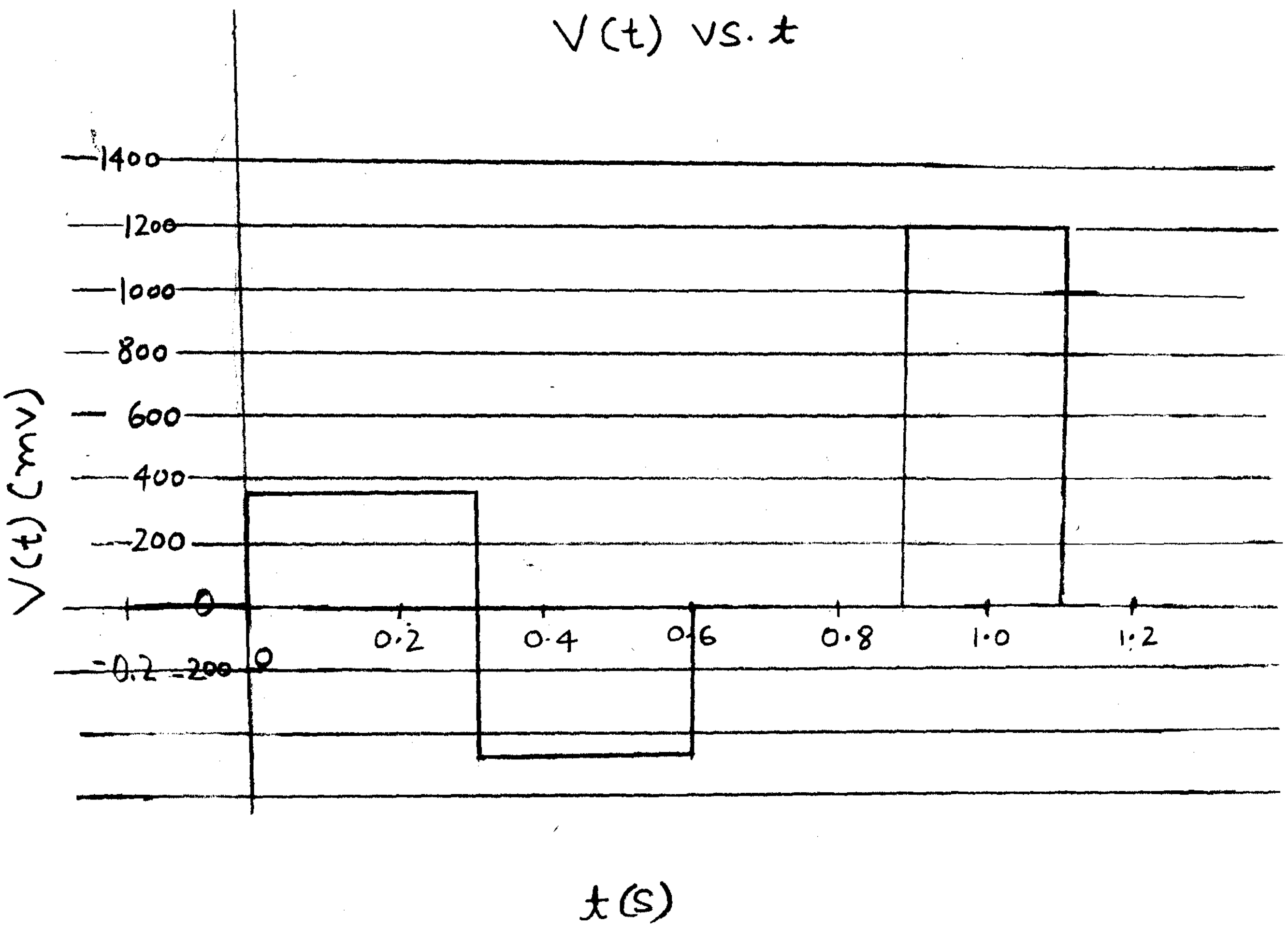
$$v(t) = 24m[50]$$

$$v(t) = 1200\,mV$$

for $t \geq 1.1\,s$

$$v(t) = 0$$

$$v(t) = \begin{cases} 0 & t \leq 0 \\ 320\,mV & 0 < t \leq 0.3\,s \\ -480\,mV & 0.3\,s < t \leq 0.6\,s \\ 0 & 0.6\,s < t \leq 0.9\,s \\ 1200\,mV & 0.9\,s < t \leq 1.1\,s \\ 0 & t > 1.1\,s \end{cases}$$


V(t) vs. t
1400
1200
1000
800
600
400
200
0
-0.2
-200
0
0.2
0.4
0.6
0.8
1.0
1.2
V(t) (mV)
t (s)

6.30 The current in a 29-mH inductor is given by the waveform in the Fig. P6.30. Find the waveform for the voltage across the inductor.

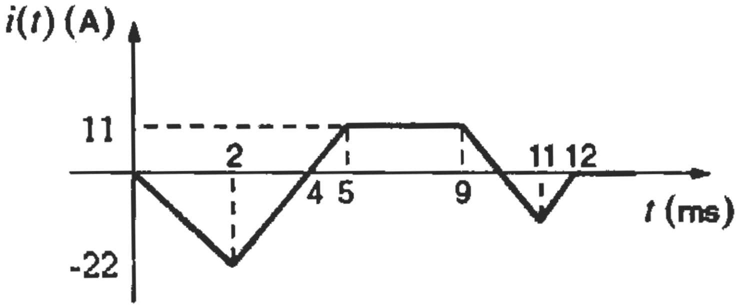


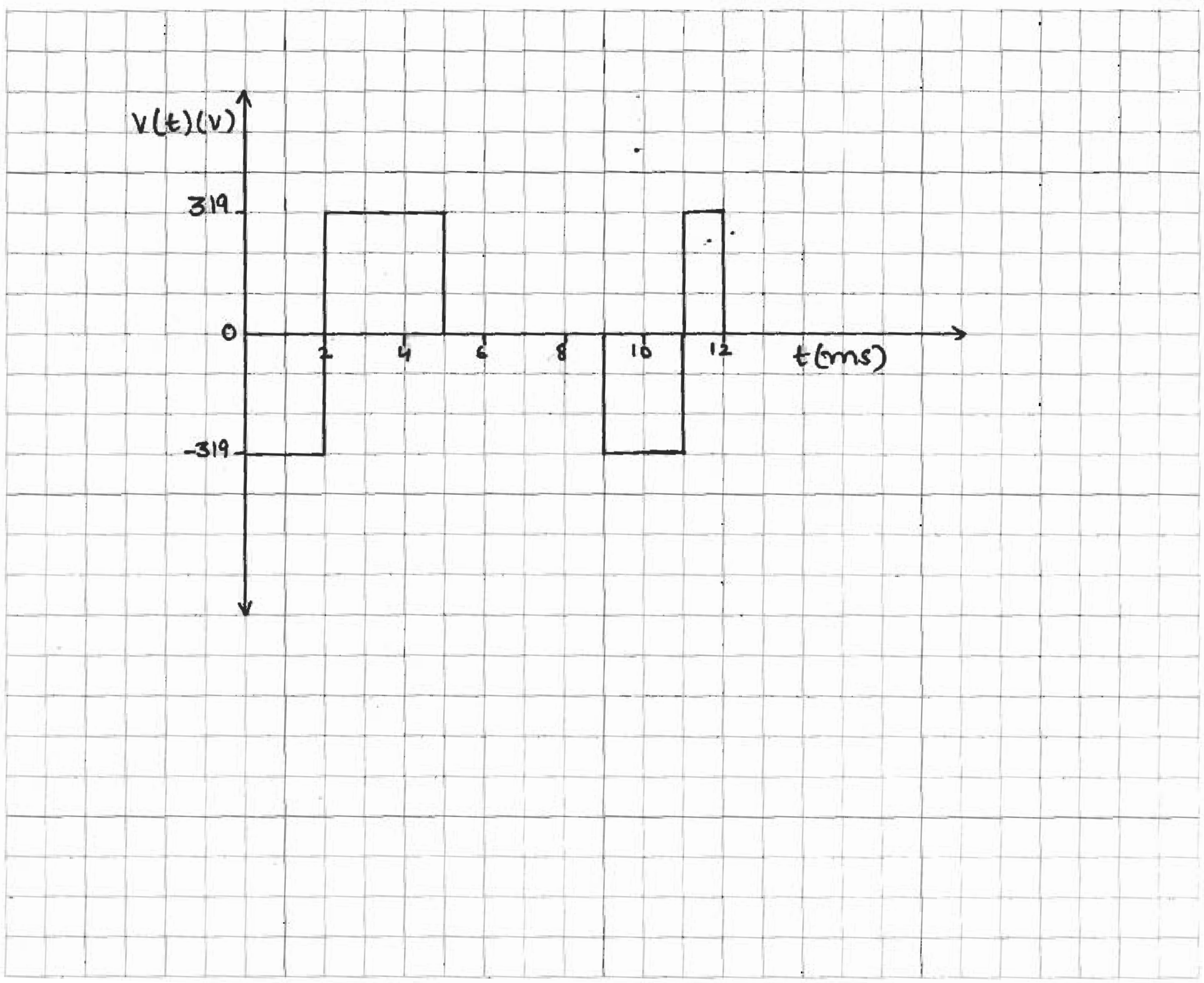
Figure P6.30

Solution: 6.30

$$V = L\frac{di}{dt}$$

$$\frac{di}{dt} = \begin{cases} 0 \text{ A/s} & t < 0 \text{ ms} \\ -11\times10^{3} \text{ A/s} & 0 \leq t < 2\text{ ms} \\ 11\times10^{3} \text{ A/s} & 2\text{ms} \leq t < 5\text{ms} \\ 0 \text{ A/s} & 5\text{ms} \leq t < 9\text{ms} \\ -11\times10^{3} \text{ A/s} & 9\text{ms} \leq t < 11\text{ ms} \\ 11\times10^{3} \text{ A/s} & 11\text{ ms} \leq t < 12\text{ ms} \\ 0 \text{ A/s} & t \geq 12\text{ms} \end{cases}$$

$$L = \begin{cases} 0 \text{ V} & t < 0 \text{ ms} \\ -319 \text{ V} & 0 \leq t < 2\text{ms} \\ 319 \text{ V} & 2\text{ms} \leq t < 5\text{ms} \\ 0 \text{ V} & 5\text{ms} \leq t < 9\text{ ms} \\ -319 \text{ V} & 9\text{ms} \leq t < 11\text{ms} \\ 319 \text{ V} & 11\text{ms} \leq t < 12\text{ms} \\ 0 \text{ V} & t \geq 12\text{ms} \end{cases}$$


v(t)(v)
319
0
-319
2
4
6
8
10
12
t(ms)

6.31 The current in a 4-mH inductor is given by the waveform in Fig. P6.31. Plot the voltage across the inductor.

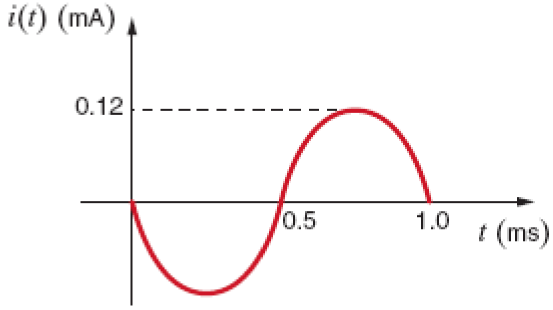


Figure P6.31

SOLUTION:

$$i(t) = -120 \sin \omega t \ \mu A$$

$$\omega = \frac{2\pi}{T}$$

$$T = 1 ms$$

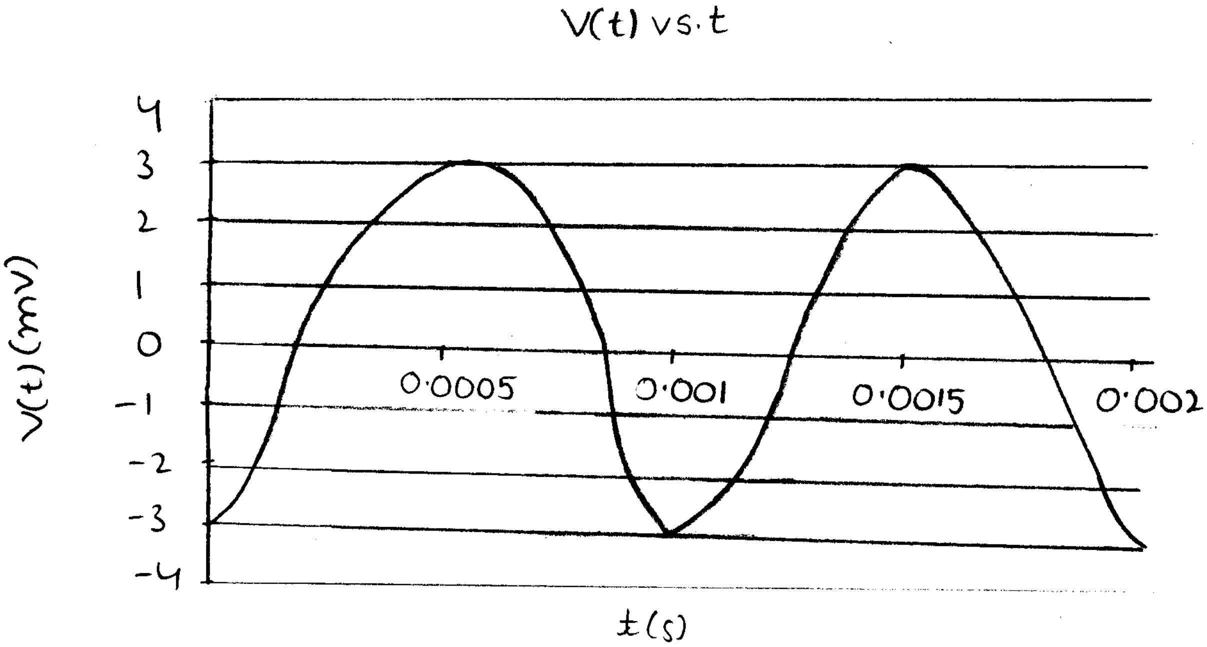
$$\omega = 2000\pi \ rad/s$$

$$i(t) = -120 \sin 2000\pi t \ \mu A$$

$$v(t) = L\frac{di(t)}{dt}$$

$$v(t) = 4m\left[-120\mu(2000\pi)\cos 2000\pi t\right]$$

$$v(t) = -3.02 \cos 2000\pi t \ mV$$



V(t) vs. t
V(t) (mV)
4
3
2
1
0
-1
-2
-3
-4
0.0005
0.001
0.0015
0.002
t (s)

6.32 The waveform for the current in the 2-H inductor shown in Fig. P6.32a is given in Fig. P6.32b. Determine the following quantities (a) the energy stored in the inductor at $t = 1.5$ ms, (b) the energy stored in the inductor at $t = 7.5$ ms, (c) $v_L(t) = 1.5$ ms, (d) $v_L(t)$ at $t = 6.25$ ms, and (e) $v_L(t)$ at $t = 2.75$ ms.

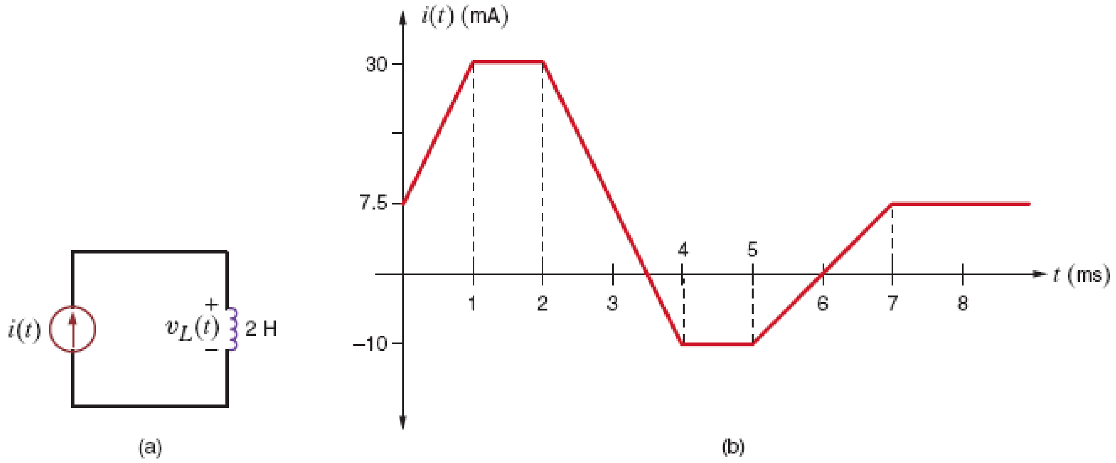


Figure P6.32

SOLUTION:

(a) $w(t) = \frac{1}{2} L i^2(t)$

$w(1.5\,ms) = \frac{1}{2}(2)(30 \times 10^{-3})^2$

$w(1.5\,ms) = 0.9\,mJ$

(b) $w(t) = \frac{1}{2} L i^2(t)$

$w(7.5\,ms) = \frac{1}{2}(2)(7.5 \times 10^{-3})^2$

$w(7.5\,ms) = 56.25\,\mu J$

(c) $V_L(t) = \dfrac{L\,di(t)}{dt}$

$i(t) = 30mA$ in the interval of interest

$$V_L(t) = 2[0]$$
$$V_L(t) = 0V$$
$$V_L(1.5ms) = 0V$$

(d) $V_L(t) = L\frac{di(t)}{dt}$

$$m = \frac{-10\times10^{-3} - 10\times10^{-3}}{5\times10^{-3} - 7\times10^{-3}} = 10$$

$$i(t) = mt + B$$

$i(t) = 10t + 60$ A in the interval of interest

$$V_L(t) = 2[10]$$
$$V_L(t) = 20V$$
$$V_L(6.25ms) = 20V$$

(e) $V_L(t) = L\frac{di(t)}{dt}$

$$m = \frac{-10\times10^{-3} - 30\times10^{-3}}{4\times10^{-3} - 2\times10^{-3}} = -20$$

$$i(t) = -20t + B$$

$$30\times10^{-3} = -20(2\times10^{-3}) + B$$

$$B = 0.07$$

$i(t) = -20t + 0.07$ A in the interval of interest

$$V_L(t) = 2[-20]$$

$$V_L(t) = -40\text{V}$$

$$V_L(2.75\text{ ms}) = -40\text{V}$$

6.33 Find the possible capacitance range of the following capacitors.

(a) 0.0068 μF with a tolerance of 10%.

(b) 120 pF with a tolerance of 20%.

(c) 39 μF with a tolerance of 20%.

SOLUTION:

(a) $C = 0.0068\ \mu F$ with 10% tolerance

Range:

$$61.2\,nF \leq C \leq 74.8\,nF$$

$$6.12\,n \leq C \leq 7.48\,n$$

(b) $C = 120\,pF$ with 20% tolerance

Range:

$$96\,pF \leq C \leq 144\,pF$$

(c) $C = 39\,\mu F$ with 20% tolerance

Range:

$$31.2\,\mu F \leq C \leq 46.8\,\mu F$$

6.34 Find the possible inductance range of the following inductors.
(a) 50 mH with a tolerance of 10%.
(b) 8 nH with a tolerance of 5%.
(c) 63 μH with a tolerance of 10%.

Solution: 6.34

(a) $L = 50\text{ mH} \pm 10\%$, $45\text{ mH} \leq L \leq 55\text{ mH}$

(b) $L = 8\text{ nH} \pm 5\%$, $7.6\text{ nH} \leq L \leq 8.4\text{ nH}$

(c) $L = 63\,\mu\text{H} + 10\%$, $56.7\,\mu\text{H} \leq L \leq 69.3\,\mu\text{H}$

6.35 The capacitor in Fig. P6.35 **(a)** is 53 nF with a tolerance of 10%. Given the voltage waveform in Fig. P6.35 **(b)**, find the current $i(t)$ for the minimum and maximum capacitor values.

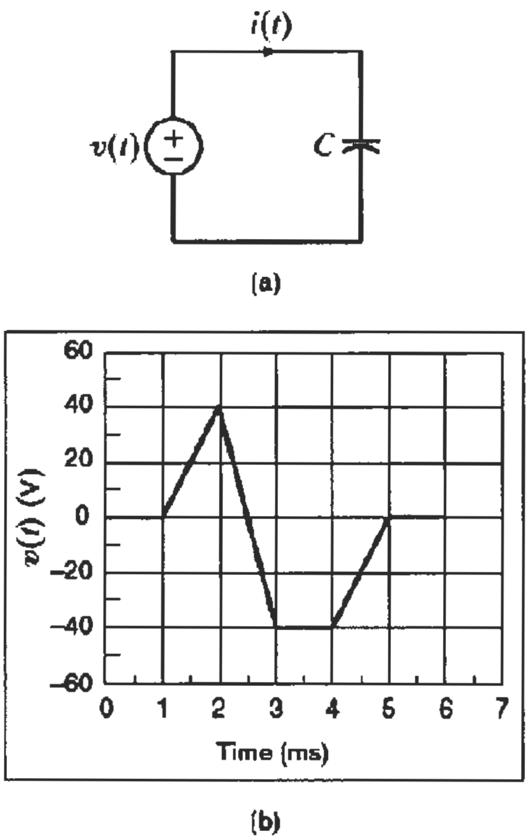


Figure P6.35

Solution: 6.35

$$i(t) = C\frac{dv}{dt}$$

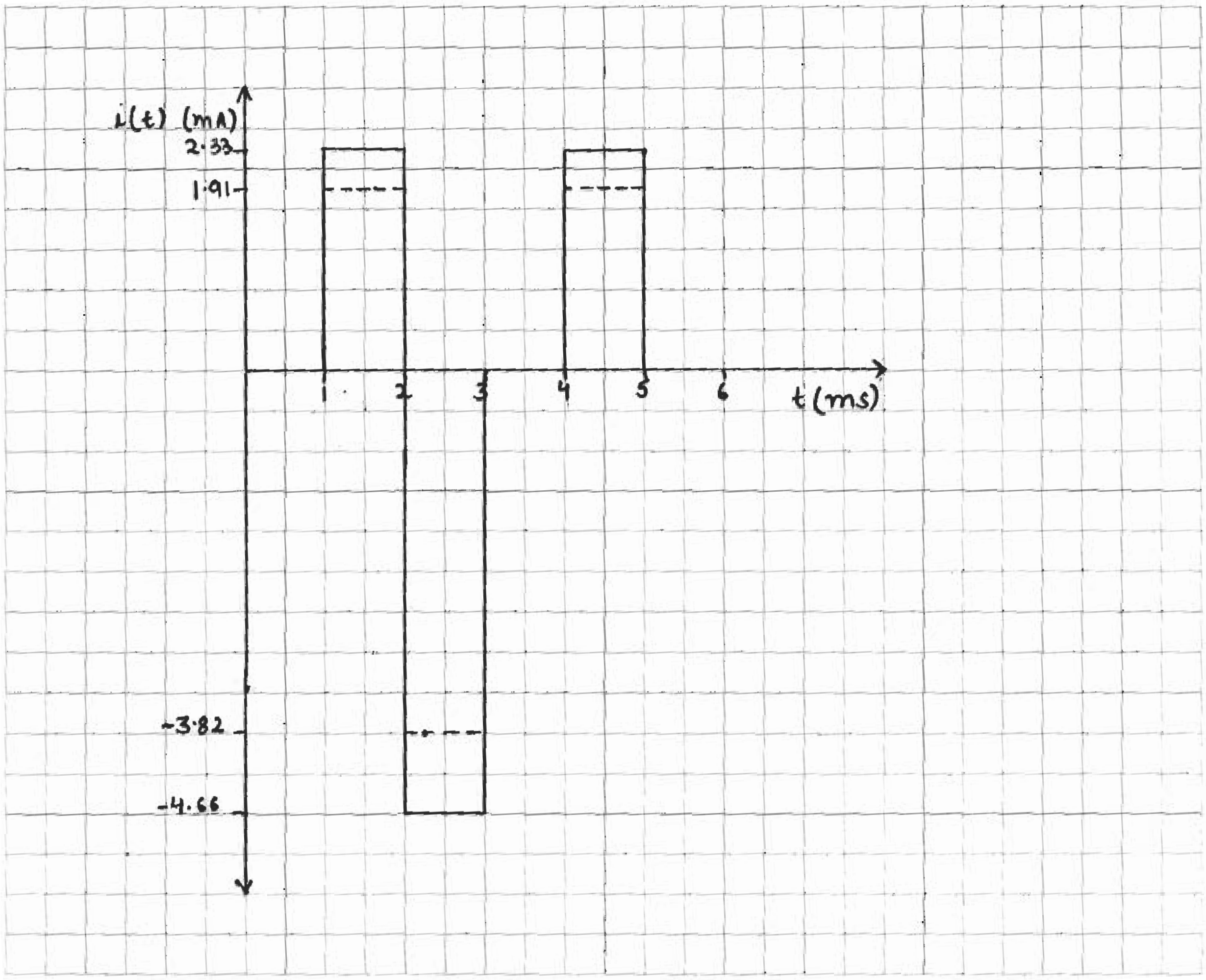
$$\frac{dv}{dt} = \begin{cases} 0 \ \text{V/s} & 0s \leq t < 1s \\ 4\times10^4 \ \text{V/s} & 1s \leq t < 2s \\ -8\times10^4 \ \text{V/s} & 2s \leq t < 3s \\ 0 \ \text{V/s} & 3s \leq t < 4s \\ 4\times10^4 \ \text{V/s} & 4s \leq t < 5s \\ 0 \ \text{V/s} & 5s \leq t < 6s \end{cases}$$

$$C_{max} = 53 + 5.3 = 58.3 \ \text{nF}$$

$$C_{min} = 53 - 5.3 = 47.7 \ \text{nF}$$

$$i(t)\ [max] = \begin{cases} 0\ mA & 0 \le t < 1s \\ 2.33\ mA & 1s \le t < 2s \\ -4.66\ mA & 2s \le t < 3s \\ 0\ mA & 3s \le t < 4s \\ 2.33\ mA & 4s \le t < 5s \\ 0\ mA & 5s \le t < 6s \end{cases}$$

$$i(t)\ [min] = \begin{cases} 0\ mA & 0 \le t < 1s \\ 1.91\ mA & 1s \le t < 2s \\ -3.82\ mA & 2s \le t < 3s \\ 0\ mA & 3s \le t < 4s \\ 1.91\ mA & 4s \le t < 5s \\ 0\ mA & 5s \le t < 6s \end{cases}$$



6.36 Given the capacitors in Fig. 6.36 are $C_1 = 2.0\ \mu F$ with a tolerance of 2% and $C_2 = 2.0\ \mu F$ with a tolerance of 20%, find the following.

(a) The nominal value of C_{eq}.

(b) The minimum and maximum possible values of C_{eq}.

(c) The percent errors of the minimum and maximum values.

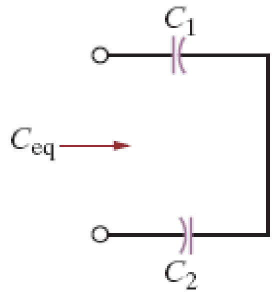


Figure P6.36

SOLUTION:

(a)

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

$$C_{eq} = \frac{(2\times10^{-6})(2\times10^{-6})}{2\times10^{-6} + 2\times10^{-6}}$$

$$C_{eq} = 1\ \mu F$$

(b)

$$C_{max} = \frac{C_{1max} + C_{2max}}{C_{1max} + C_{2max}}$$

$$C_{max} = \frac{(2.04\times10^{-6})(2.4\times10^{-6})}{2.04\times10^{-6} + 2.4\times10^{-6}}$$

$$C_{max} = 1.1\,\mu F$$

$$C_{min} = \frac{C_1 min\; C_2 min}{C_1 min\; C_2 min}$$

$$C_{min} = \frac{(1.96 \times 10^{-6})\,(1.6 \times 10^{-6})}{(1.96 \times 10^{-6}) + 1.6 \times 10^{-6}}$$

$$C_{min} = 0.881\,\mu F$$

(C)

$$+\,\%\,error = \frac{C_{max} - C_{eq}}{C_{eq}}$$

$$+\,\%\,error = \frac{1.1 \times 10^{-6} - 1 \times 10^{-6}}{1 \times 10^{-6}}$$

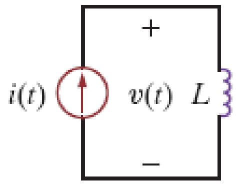
$$+\,\%\,error = 10\,\%$$

$$-\,\%\,error = \frac{C_{min} - C_{eq}}{C_{eq}}$$

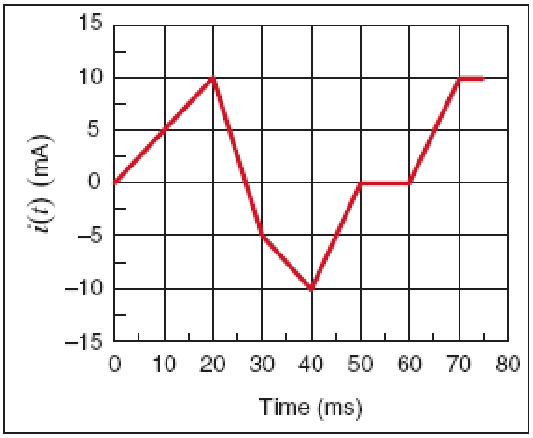
$$-\,\%\,error = \frac{0.881 \times 10^{-6} - 1 \times 10^{-6}}{1 \times 10^{-6}}$$

$$-\,\%\,error = -11.9\,\%$$

6.37 The inductor in Fig. P6.37a is 4.7 μH with a tolerance of 20%. Given the current waveform in Fig. P6.37b, graph the voltage $v(t)$ for the minimum and maximum inductor values.



(a)



(b)

Figure P6.37

SOLUTION:

$$V(t) = L\frac{di(t)}{dt}$$

for $0 \le t < 20ms$

$$V_{max}(t) = (1.2)(4.7\mu)(1/2) = 2.82\,\mu V$$

$$V_{min}(t) = (0.8)(4.7\mu)(1/2) = 1.88\,\mu V$$

for $20ms \le t \le 30ms$

$$V_{max}(t) = (1.2)(4.7\mu)(-1.5) = -8.46\,\mu V$$

$$V_{min}(t) = (0.8)(4.7\mu)(-1.5) = -5.46\,\mu V$$

for $30ms \le t \le 40ms$

$V_{max}(t) = (1.2)(4.7\mu)(-0.5) = -2.82\mu V$

$V_{min}(t) = (0.8)(4.7\mu)(-0.5) = -1.88\mu V$

for $40ms \le t \le 50ms$

$V_{max}(t) = (1.2)(4.7\mu)(1) = 5.64\mu V$

$V_{min}(t) = (0.8)(4.7\mu)(1) = 3.76\mu V$

for $50ms \le t < 60ms$

$V(t) = 0V$

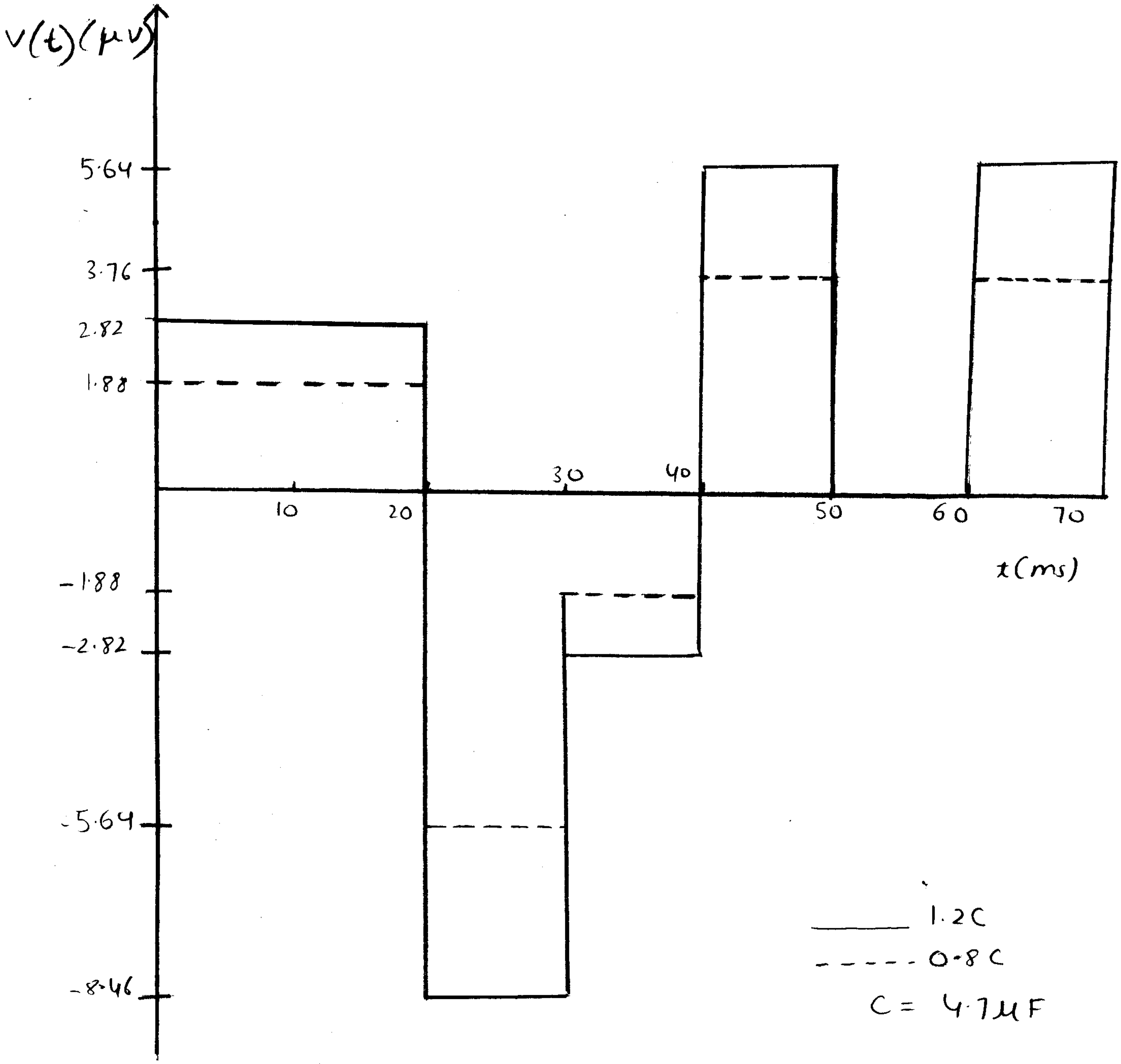
for $60ms \le t \le 70ms$

$V_{max}(t) = (1.2)(4.7\mu)(1) = 5.64\mu V$

$V_{min}(t) = (0.8)(4.7\mu)(1) = 3.76\mu V$

for $t > 70ms$

$V(t) = 0V$


v(t)(μv)
5.64
3.76
2.82
1.88
-1.88
-2.82
-5.64
-8.46
10
20
30
40
50
60
70
t(ms)
1.2C
0.8C
C = 4.7μF

6.38 If the total energy stored in the circuit in Fig. P6.38 is 80 mJ, what is the value of L?

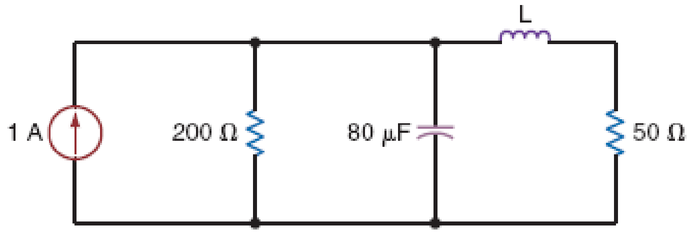
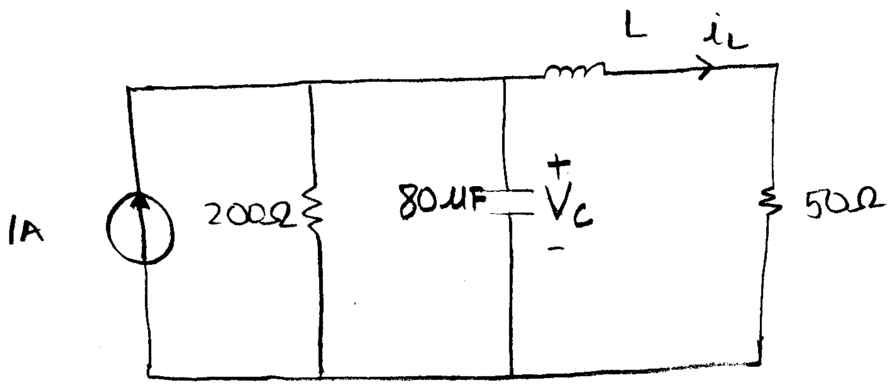


Figure P6.38

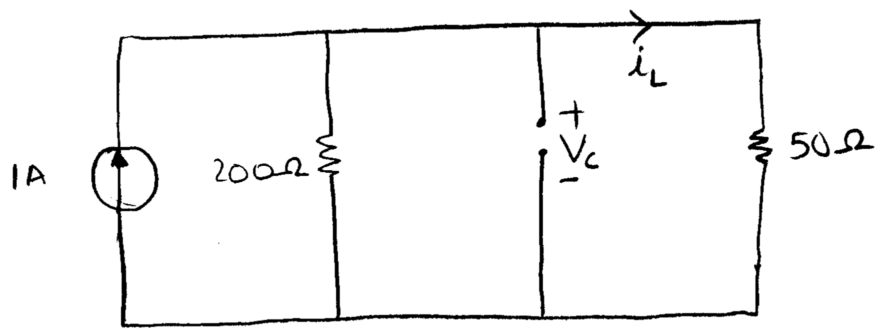
SOLUTION:



$i_C = C\dfrac{dV_c}{dt} = 0$, V_c is a constant

$V_L = L\dfrac{di_L}{dt} = 0$, i_L is a constant

Redraw the circuit as:



$$R_{eq} = 200 \parallel 50 = \frac{200(50)}{200+50}$$

$$R_{eq} = 40\Omega$$

$$V_C = (1)(40) \qquad V_C = 40V$$

$$W_C = \frac{1}{2} C V_C^2$$

$$W_C = \tfrac{1}{2}(80\mu)(40)^2$$

$$W_C = 64mJ$$

$$i_L = \left(\frac{200}{200+50}\right)(1)$$

$$i_L = 0.8A$$

$$W_L = \tfrac{1}{2} L i_L^2$$

$$L = \frac{2W_L}{i_L^2}$$

$$W_{total} = W_L + W_C$$

$$W_L = 80m - 64m$$

$$W_L = 16mH$$

$$L = \frac{2(16m)}{(0.8)^2}$$

$$L = 50mH$$

6.39 Find the value of C if the energy stored in the capacitor in Fig. P6.39 equals the energy stored in the inductor.

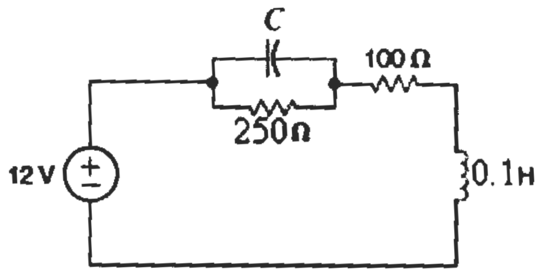
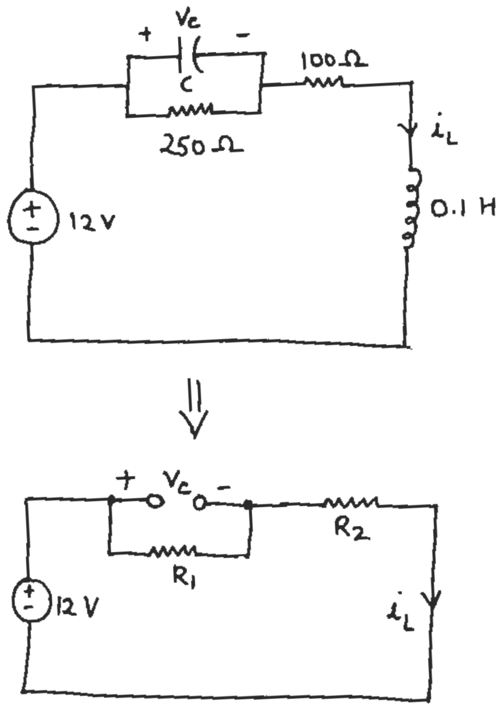


Figure P6.39

Solution: 6.39



Since voltage source is constant, V_c and i_L are constant.

$$i_c = C\frac{dV_c}{dt} = 0 \quad \text{and}$$

$$V_L = L\frac{di_L}{dt} = 0$$

$$i_L = \frac{12}{R_1 + R_2} = 34.29 \text{ mA}$$

$$V_c = \frac{12 R_1}{R_1 + R_2} = 8.57 \text{ V}$$

$$W_C = \frac{1}{2} C V_c^2 = W_L = \frac{1}{2} L i_L^2 \Rightarrow C = L\left(\frac{i_L}{V_c}\right)^2$$

$$\boxed{C = 1.60 \mu F}$$

6.40 Given the network in Fig. P6.40, find **(a)** the power dissipated in the 3-Ω resistor and **(b)** the energy stored in the capacitor.

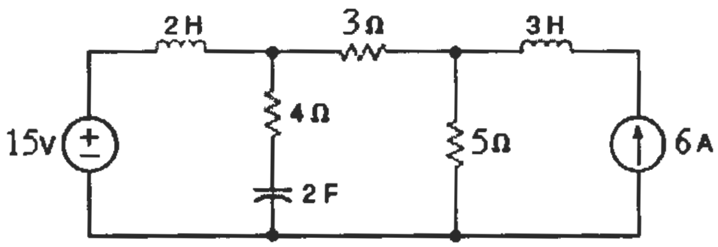
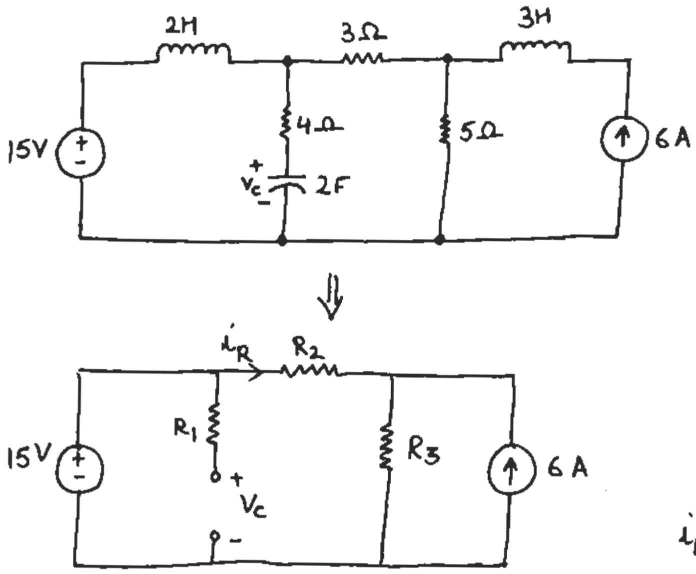


Figure P6.40

Solution: 6.40



Since all sources are constant, all voltages and current are constant

$V_L = L \frac{di_L}{dt} = 0$ and

$i_c = C \frac{dV_c}{dt} = 0$

$P_{R_2} = R_2 i_R^2$, $W_c = \frac{1}{2} C V_c^2$

By superposition

$i_R = 15 \left[\frac{1}{R_2+R_3}\right] - 6 \left[\frac{R_3}{R_2+R_3}\right]$

$= -1.875$ A

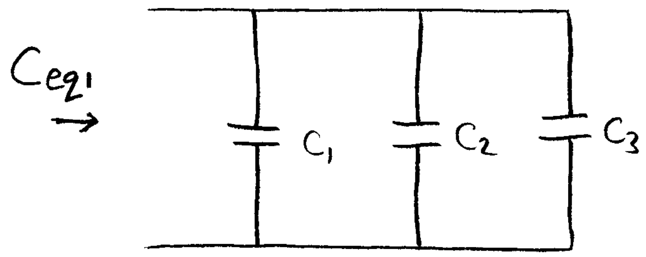
$\boxed{P_{R_2} = 10.54 \text{ W}}$

$\boxed{W_c = 225 \text{ J}}$

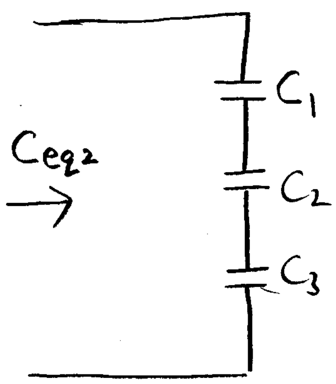
6.41 What values of capacitance can be obtained by interconnecting a 4-µF capacitor, a 6-µF capacitor, and a 12-µF capacitor?

SOLUTION:

$C_1 = 4\mu F$, $C_2 = 6\mu F$, and $C_3 = 12\mu F$



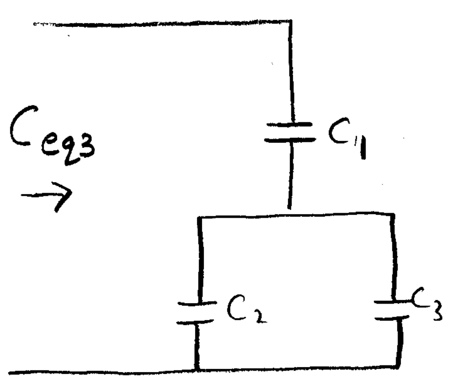
$$C_{eq1} = C_1 + C_2 + C_3 = 4\mu + 6\mu + 12\mu = 22\mu F$$



$$C_{eq2} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

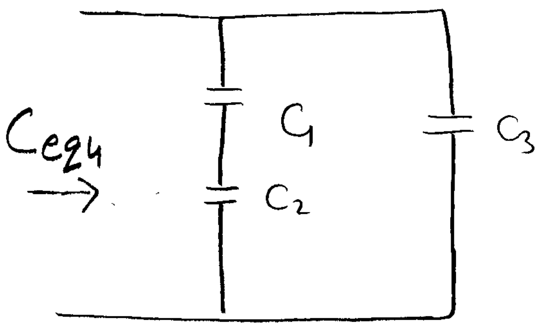
$$C_{eq2} = \frac{1}{\frac{1}{4\mu} + \frac{1}{6\mu} + \frac{1}{12\mu}}$$

$$C_{eq2} = 2\mu F$$



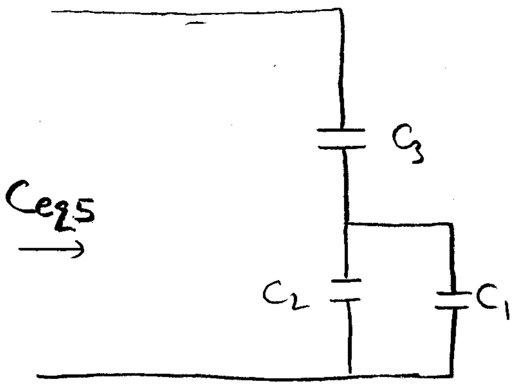
$$C_{eq3} = \frac{(C_2 + C_3)(C_1)}{C_1 + C_2 + C_3}$$

$$C_{eq3} = 3.27\mu F$$



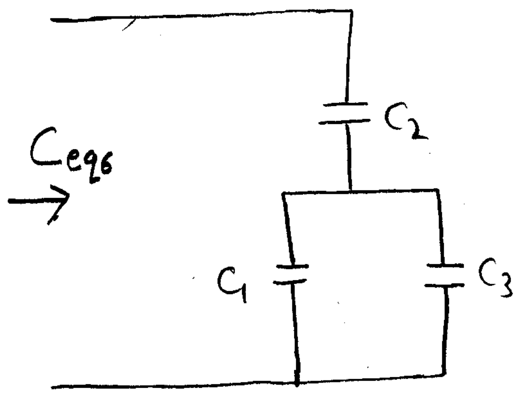
$$C_{eq4} = C_3 + \frac{C_1 C_2}{C_1 + C_2}$$

$$C_{eq4} = 14.4\,\mu F$$



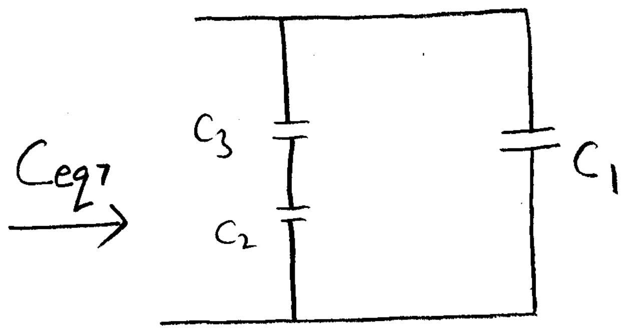
$$C_{eq5} = \frac{(C_1 + C_2)(C_3)}{C_1 + C_2 + C_3}$$

$$C_{eq5} = 5.45\,\mu F$$



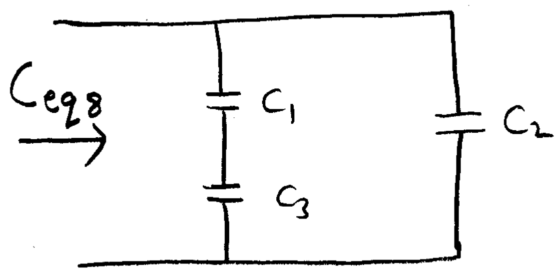
$$C_{eq6} = \frac{(C_1 + C_3)(C_2)}{C_1 + C_2 + C_3}$$

$$C_{eq6} = 4.36\,\mu F$$



$$C_{eq7} = \frac{C_1(C_2+C_3)}{C_1+C_2+C_3}$$

$$C_{eq7} = 8\mu F$$



$$C_{eq8} = \frac{C_2(C_1+C_3)}{C_1+C_2+C_3}$$

$$C_{eq8} = 9\mu F$$

Capacitance values possible:

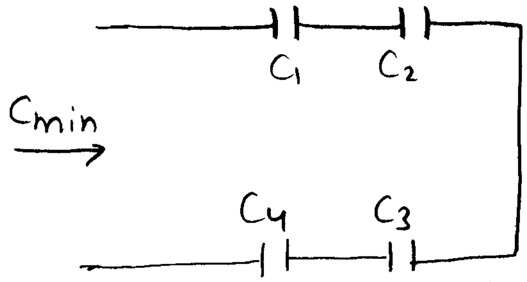
$C_{eq1} = 22\mu F$
$C_{eq2} = 2\mu F$
$C_{eq3} = 3.27\mu F$
$C_{eq4} = 14.4\mu F$
$C_{eq5} = 5.45\mu F$
$C_{eq6} = 4.36\mu F$
$C_{eq7} = 8\mu F$
$C_{eq8} = 9\mu F$

6.42 Given four 2-μF capacitors, find the maximum value and minimum value that can be obtained by interconnecting the capacitors in series/parallel combinations.

SOLUTION:

$$C_1 = C_2 = C_3 = C_4 = 2\,\mu F$$

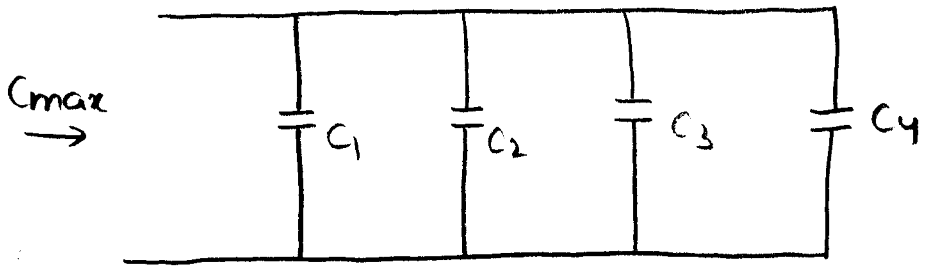
Minimum when all connected in series:



$$C_{min} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}}$$

$$C_{min} = 0.5\,\mu F$$

Maximum when all connected in parallel:



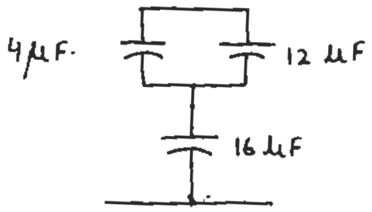
$$C_{max} = C_1 + C_2 + C_3 + C_4$$

$$C_{max} = 8 \mu F$$

6.43 Given a 4-, 12-, and 16-μF capacitor, can they be interconnected to obtain an equivalent 8-μF capacitor?

Solution: 6.43

Yes



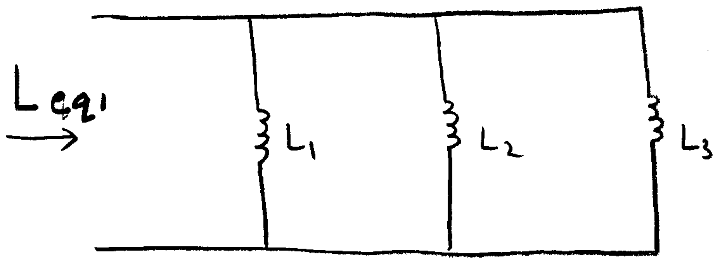
$$C_{eq} = \frac{(4\times10^{-6} + 12\times10^{-6})\,16\times10^{-6}}{(4\times10^{-6}+12\times10^{-6}) + 16\times10^{-6}}$$

$$= 8\,\mu F$$

6.44 Determine the values of inductance that can be obtained by interconnecting a 4-mH inductor, a 6-mH inductor, and a 12-mH inductor.

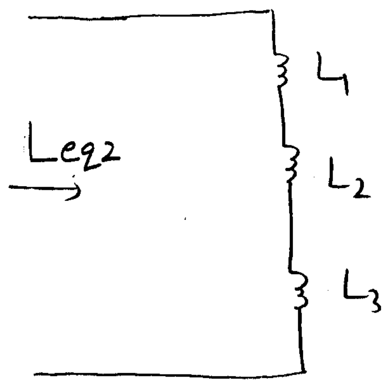
SOLUTION:

$L_1 = 4mH$, $L_2 = 6mH$, and $L_3 = 12mH$



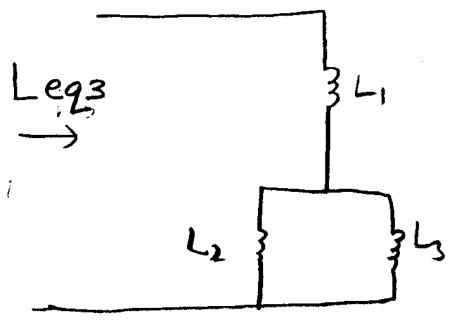
$$L_{eq1} = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}}$$

$$L_{eq} = 2mH$$



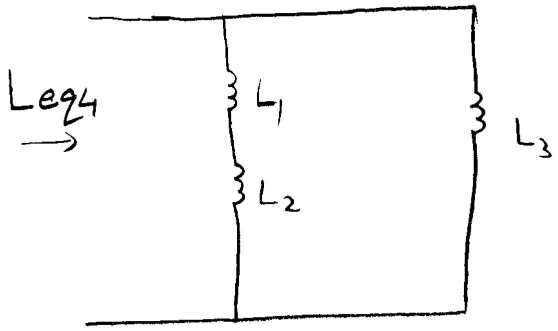
$$L_{eq2} = L_1 + L_2 + L_3$$

$$L_{eq2} = 22mH$$



$$L_{eq3} = \frac{L_2 L_3}{L_2 + L_3} + L_1$$

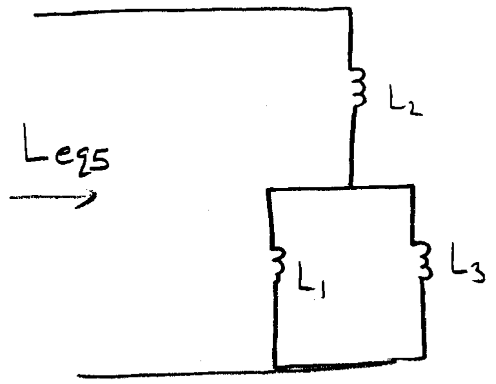
$$L_{eq3} = 8mH$$



$$L_{eq4} = (L_1 + L_2) \parallel L_3$$

$$L_{eq4} = \frac{(L_1 + L_2)(L_3)}{L_1 + L_2 + L_3}$$

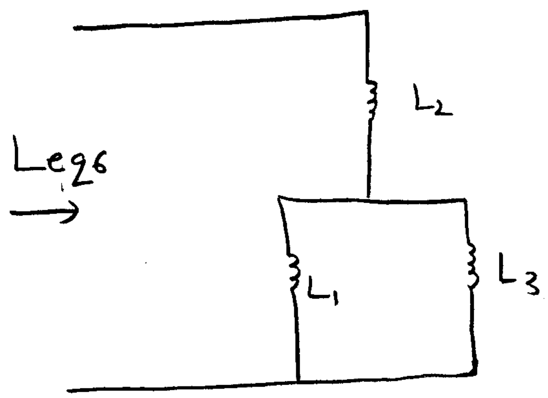
$$L_{eq4} = 5.45 \text{ mH}$$



$$L_{eq5} = (L_1 \parallel L_2) + L_3$$

$$L_{eq5} = \frac{L_1 L_2}{L_1 + L_2} + L_3$$

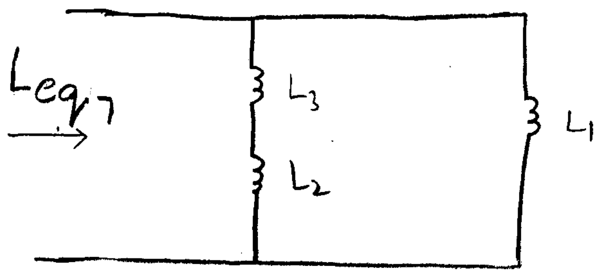
$$L_{eq5} = 14.4 \text{ mH}$$



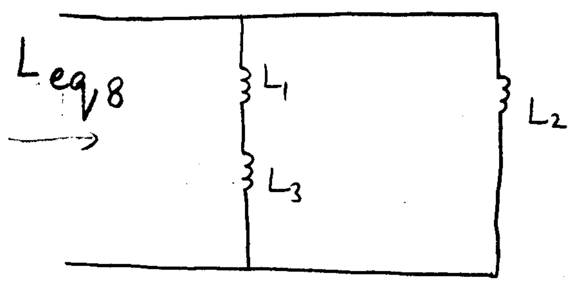
$$L_{eq6} = (L_1 \parallel L_3) + L_2$$

$$L_{eq6} = \frac{L_1 L_3}{L_1 + L_3} + L_2$$

$$L_{eq6} = 9 \text{ mH}$$



$$L_{eq_7} = \frac{(L_2 + L_3)L_1}{L_1 + L_2 + L_3} = 3.27\,mH$$



$$L_{eq_8} = \frac{(L_1 + L_3)(L_2)}{L_1 + L_2 + L_3} = 4.36\,mH$$

Inductance values possible:

$L_{eq_1} = 2\,mH$

$L_{eq_2} = 22\,mH$

$L_{eq_3} = 8\,mH$

$L_{eq_4} = 5.45\,mH$

$L_{eq_5} = 14.4\,mH$

$L_{eq_6} = 9\,mH$

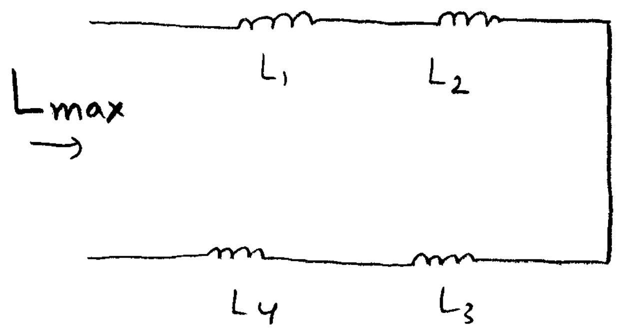
$L_{eq_7} = 3.27\,mH$

$L_{eq_6} = 4.36\,mH$

6.45 Given four 4-mH inductors, determine the maximum and minimum values of inductance that can be obtained by interconnecting the inductors in series/parallel combinations.

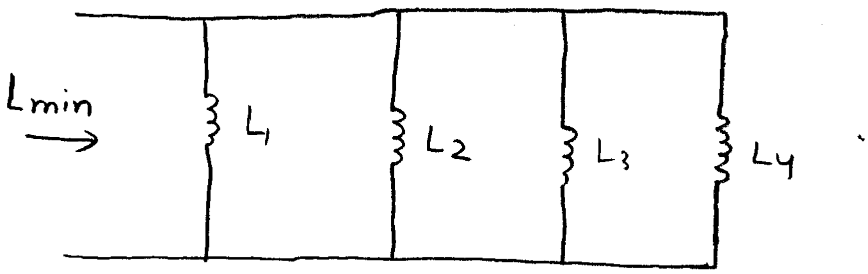
SOLUTION:

$$L_1 = L_2 = L_3 = L_4 = 4\,mH$$



$$L_{max} = L_1 + L_2 + L_3 + L_4$$

$$L_{max} = 16\,mH$$



$$L_{min} = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \frac{1}{L_4}}$$

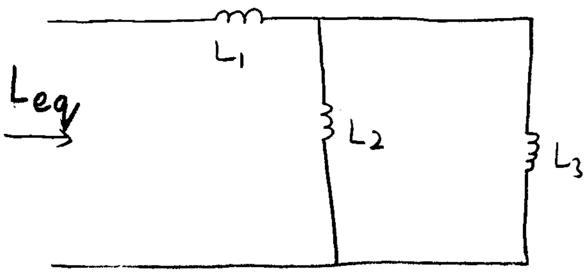
$$L_{min} = 1\,mH$$

6.46 Given a 6-, 9- and 18-mH inductor, can they be interconnected to obtain an equivalent 12-mH inductor?

SOLUTION:

$L_1 = 6\,mH$, $L_2 = 9\,mH$, and $L_3 = 18\,mH$

$L_{eq} = 12\,mH$



$$L_{eq} = (L_2 \parallel L_3) + L_1$$

$$L_{eq} = \frac{L_2 L_3}{L_2 + L_3} + L_1$$

$$L_{eq} = 12\,mH$$

6.47 Find the total capacitance C_T of the network shown in the Fig. P6.47 below.

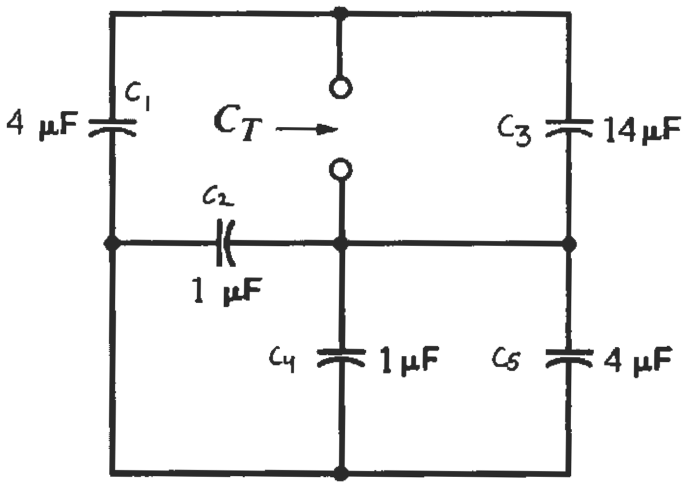
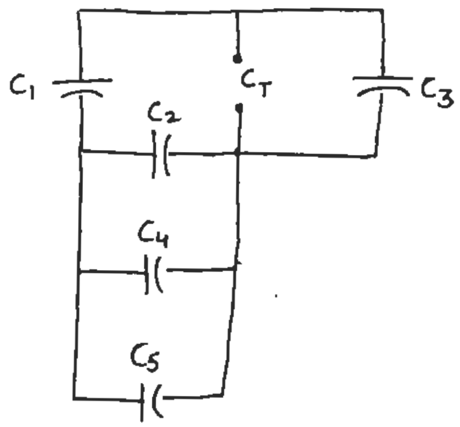


Figure P6.47

Solution: 6.47



$$C_x = C_2 + C_4 + C_5$$
$$= 6\,\mu F$$
$$C_T = C_3 + \frac{C_1 C_x}{C_1 + C_x}$$
$$= \left[14 + \frac{4 \times 6}{4+6}\right] \mu F$$
$$\boxed{C_T = 16.4\ \mu F}$$

6.48 Find the total capacitance C_T of the network in Fig. P6.48.

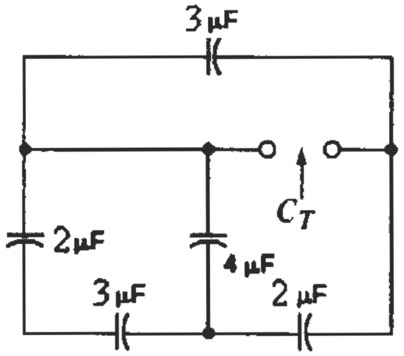
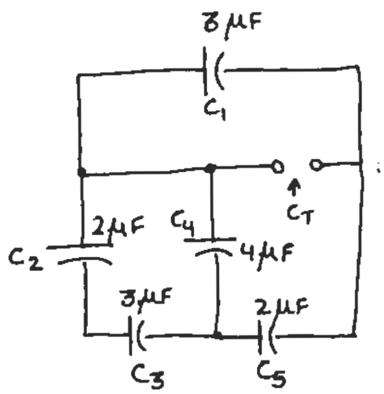
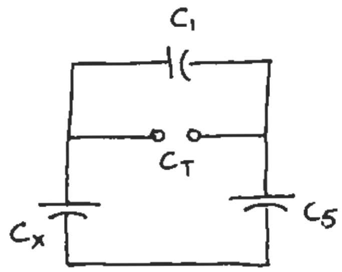


Figure P6.48

Solution: 6·48



⇒



$$C_x = C_4 + \frac{C_2 C_3}{C_2 + C_3}$$

$$= 5.2\ \mu F$$

$$C_T = C_1 + \frac{C_x C_5}{C_x + C_5}$$

$$\boxed{C_T = 4.44\ \mu F}$$

6.49 Find the total capacitance C_T shown in the network in Fig. P6.49.

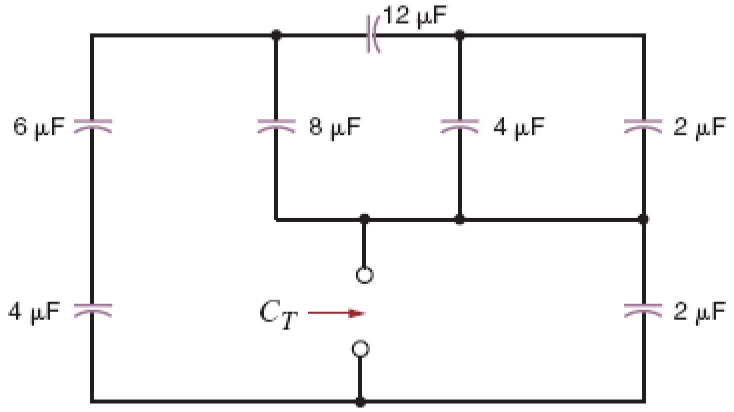
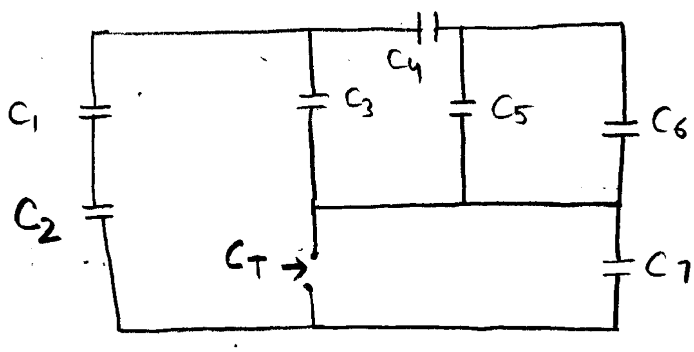


Figure P6.49

SOLUTION:



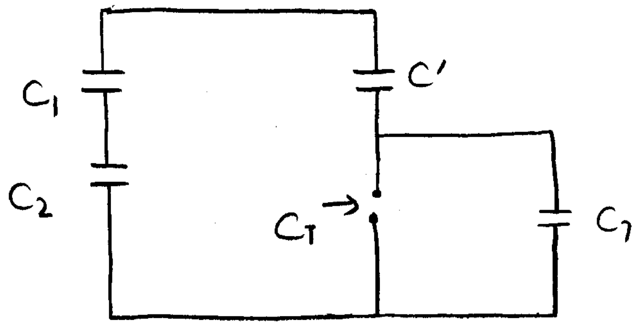
$C_1 = 6\mu F$, $C_2 = 4\mu F$, $C_3 = 8\mu F$,
$C_4 = 12\mu F$, $C_5 = 4\mu F$, $C_6 = 2\mu F$,
and $C_7 = 2\mu F$

$$C' = \frac{(C_5 + C_6)(C_4)}{C_4 + C_5 + C_6} + C_3$$

$$C' = \frac{(4\mu + 2\mu)(12\mu)}{12\mu + 4\mu + 2\mu} + 8\mu$$

$$C' = 12\mu F$$

Redraw:



$$\frac{1}{C''} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C'}$$

$$\frac{1}{C''} = \frac{1}{6\mu} + \frac{1}{4\mu} + \frac{1}{12\mu}$$

$$\frac{1}{C''} = 500{,}000$$

$$C'' = 2\mu F$$

$$C_T = C'' + C_7 = 2\mu + 2\mu$$

$$C_T = 4\mu F$$

6.50 Compute the equivalent capacitance of the network in Fig. P6.50 if all the capacitors are 4 μF.

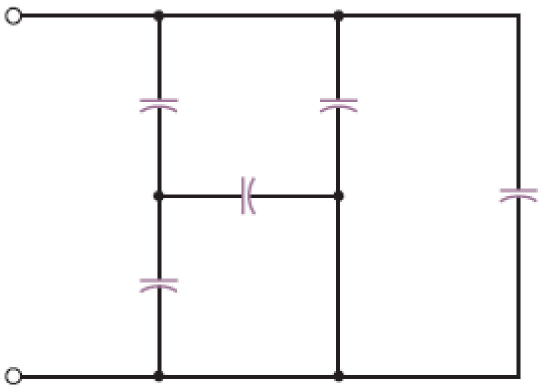
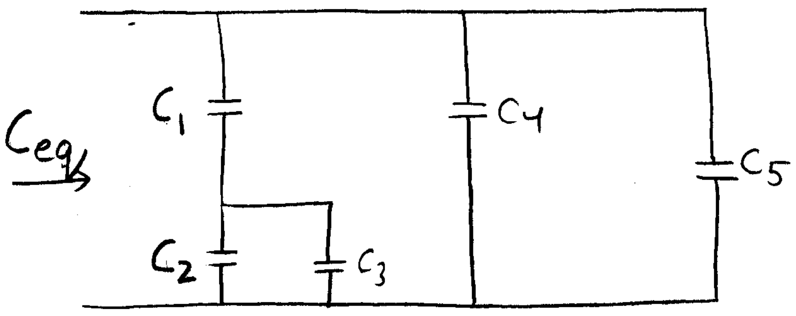


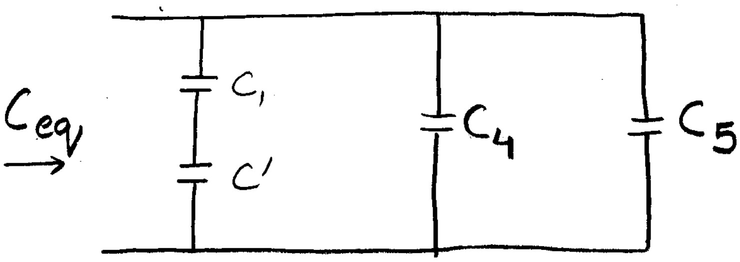
Figure P6.50

SOLUTION:



$$C_1 = C_2 = C_3 = C_4 = C_5 = 4\mu F$$

$$C' = C_2 + C_3 = 8\mu F$$



$$C'' = \frac{C_1 C'}{C_1 + C'} = 2.67\mu F$$

$$C_{eq} = C'' + C_4 + C_5$$

$$C_{eq} = 10.67\,\mu F$$

6.51 Find C_T in the network in Fig. P6.51 if (a) the switch is open and (b) the switch is closed.

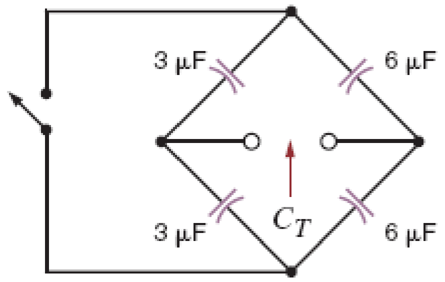
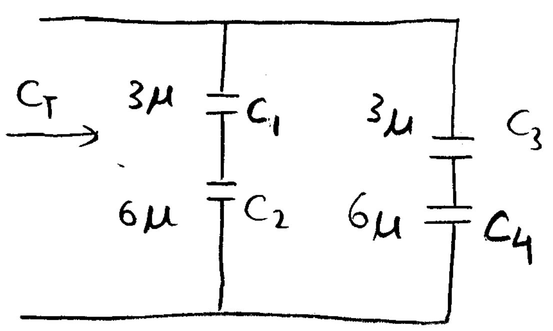
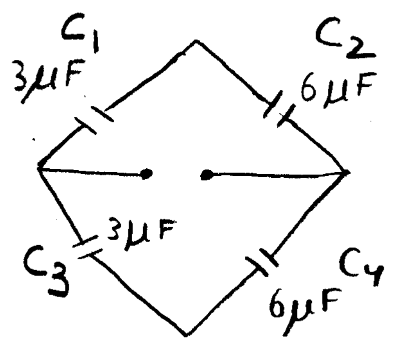


Figure P6.51

SOLUTION:

(a) switch open:

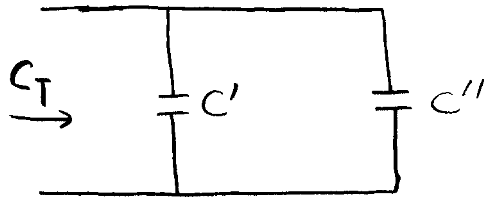




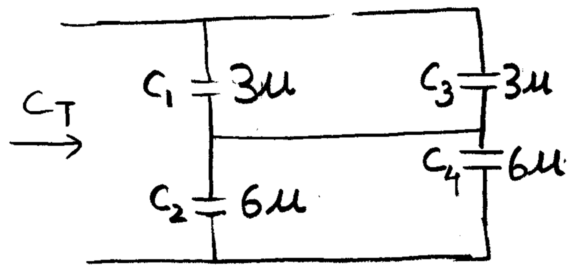
$$C' = \frac{6(3)}{6+3} = 2\mu F$$

$$C'' = 2\mu F$$

$$C_T = C' + C'' = 4\mu F$$

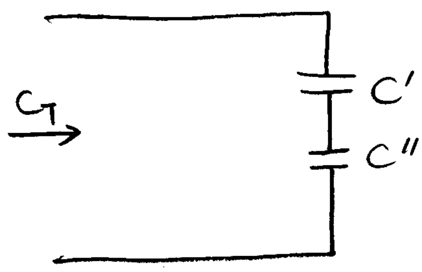


(b) Switch closed:



$$C' = C_1 + C_3 = 6\mu F$$

$$C'' = C_2 + C_4 = 12\mu F$$



$$C_T = \frac{C'C''}{C' + C''}$$

$$C_T = 4\mu F$$

6.52 In the network in the Fig. P6.52 below, find the capacitance C_T if

(a) the switch is open and

(b) the switch is closed.

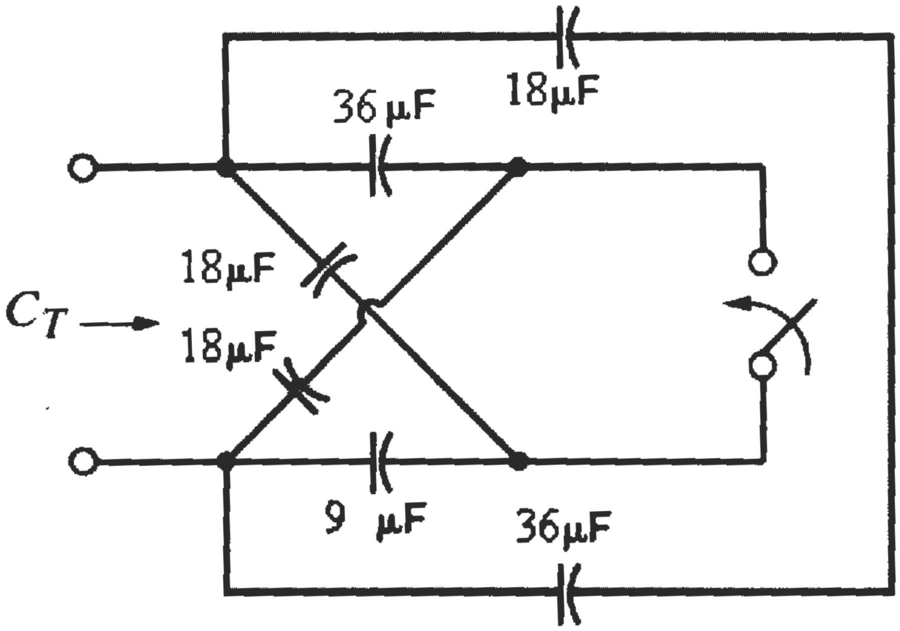
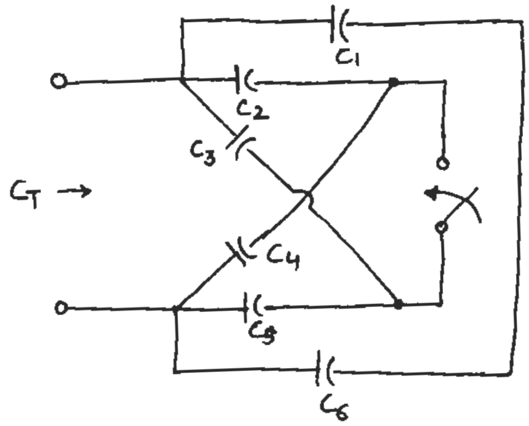
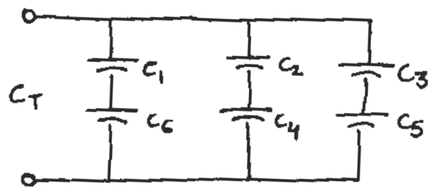


Figure P6.52

Solution: 6·52



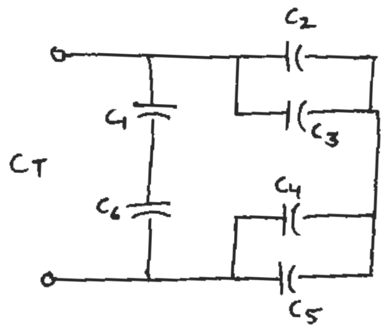
(a)



$$C_T = \frac{C_1C_6}{C_1+C_6} + \frac{C_2C_4}{C_2+C_4} + \frac{C_3C_5}{C_3+C_5}$$

$$\boxed{C_T = 30\,\mu F}$$

(b)



$$C_x = \frac{(C_2+C_3)(C_4+C_5)}{C_2+C_3+C_4+C_5}$$

$$= 18\,\mu F$$

$$C_T = C_x + \frac{C_1C_6}{C_1+C_6}$$

$$\boxed{C_T = 30\,\mu F}$$

6.53 Select the value of C to produce the desired total capacitance of $C_T = 10\ \mu F$ in the circuit in Fig. P6.53.

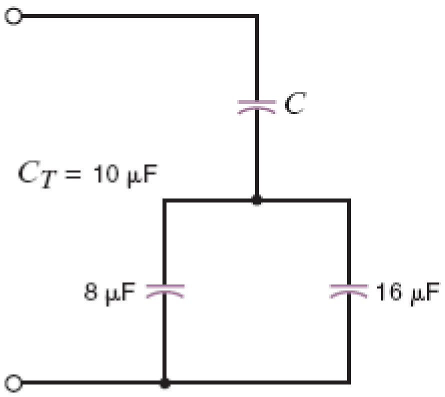
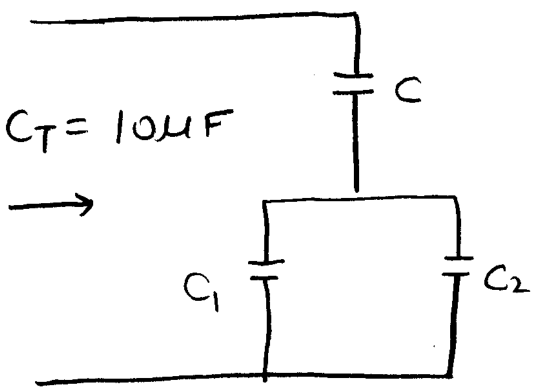


Figure P6.53

SOLUTION:



$C_1 = 8\mu F$ and $C_2 = 16\mu F$

$$C_T = \frac{(C_1 + C_2)(C)}{C_1 + C_2 + C}$$

$$C_T(C_1 + C_2) + CC_T = (C_1 + C_2)\ C$$

$$C[C_1 + C_2 - C_T] = C_T(C_1 + C_2)$$

$$C = \frac{C_T(C_1 + C_2)}{C_1 + C_2 - C_T}$$

$$C = \frac{10\mu(8\mu + 16\mu)}{8\mu + 16\mu - 10\mu}$$

$$C = 17.14\,\mu F$$

6.54 Select the value of C to produce the desired total capacitance of $C_T = 1\ \mu\text{F}$ in the circuit in Fig. P6.54.

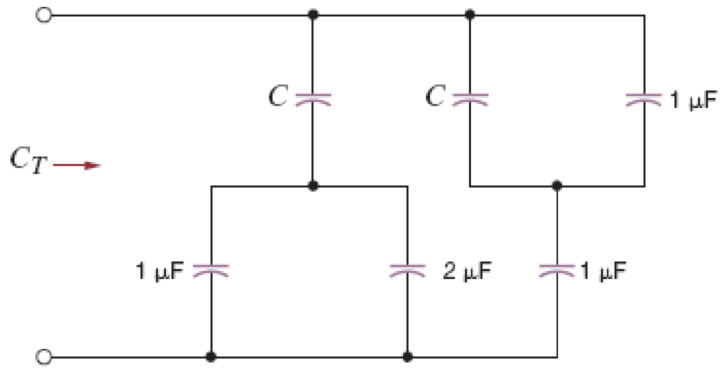
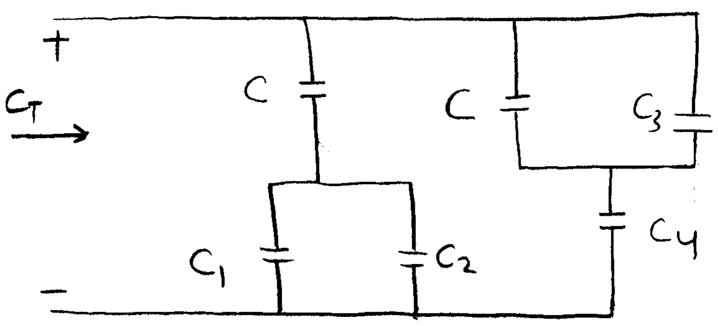


Figure P6.54

SOLUTION:



$C_1 = 1\mu F$, $C_2 = 2\mu F$, $C_3 = 1\mu F$, $C_4 = 1\mu F$

$$C_x = \frac{(C+C_3)(C_4)}{C+C_3+C_4}$$

$$C_y = \frac{(C_1+C_2)(C)}{C+C_1+C_2}$$

$$C_T = C_x + C_y$$

$$C_T = \frac{(C+C_3)(C_4)}{C+C_3+C_4} + \frac{(C_1+C_2)(C)}{C+C_1+C_2}$$

$$1\mu = \frac{(C+1\mu)(1\mu)}{C+1\mu+1\mu} + \frac{(1\mu+2\mu)(C)}{C+1\mu+2\mu}$$

$$1\mu = \frac{(C+1\mu)(1\mu)}{C+2\mu} + \frac{(3\mu)(C)}{C+3\mu}$$

$$1 = \frac{C+1}{C+2} + \frac{3C}{C+3}$$

Note: C is in μF

$$C+2 = C+1 + \frac{3C(C+2)}{C+3}$$

$$(C+2)(C+3) = (C+1)(C+3) + 3C(C+2)$$

$$C^2+5C+6 = C^2+4C+3+3C^2+6C$$

$$3C^2+5C-3 = 0$$

$$C = \frac{-5 \pm \sqrt{25-4(3)(-3)}}{2(3)}$$

$$C = \frac{-5 \pm 7.81}{6}$$

$$C = 468\ nF$$

6.55 The two capacitors in Figure were charged and then connected as shown in Fig. P6.55. Determine **(a)** the equivalent capacitance, **(b)** the initial voltage at the terminals, and **(c)** the total energy stored in the network.

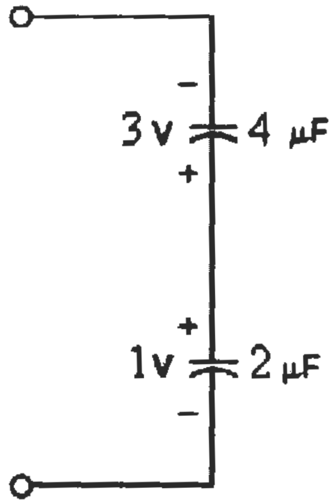
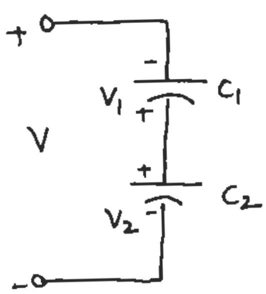


Figure P6.55

Solution: 6.55



$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

$$\boxed{C_{eq} = 1.33\ \mu F}$$

$$V = -3 + 1 = -2V$$

$$\boxed{V = -2V}$$

$$W = \frac{1}{2} C_1 V_1^2 + \frac{1}{2} C_2 V_2^2$$

$$\boxed{W = 19\ \mu J}$$

6.56 The two capacitors shown in Fig. P6.56 have been connected for some time and have reached their present values, Find V_o.

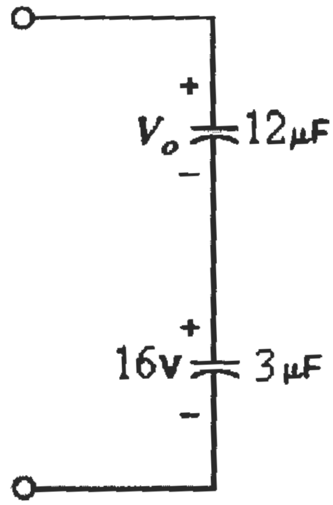


Figure P6.56

Solution: 6.56

Identical charge on each capacitor.

$$Q = CV = (3\times10^{-6})(16) = (12\times10^{-6})\,V_o$$

$$\Rightarrow \boxed{V_o = 4.0\ \text{V}}$$

6.57 The three capacitors shown Fig. P6.57 have been connected for some time and have reached their present values. Find **(a)** V_1 and **(b)** V_2.

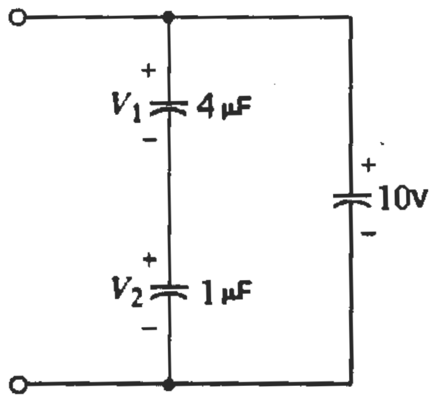
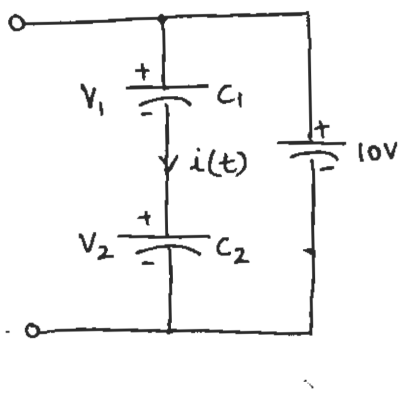


Figure P6.57

Solution: 6.57



$C_1 = 4\mu F \quad , \quad C_2 = 1\mu F$

$V_1 = \frac{1}{C_1}\int i\,dt \qquad V_2 = \frac{1}{C_2}\int i\,dt$

$\frac{V_1}{V_2} = \frac{C_2}{C_1} = \frac{1}{4}$

$V_1 + V_2 = 10V$

$\boxed{V_1 = 2V}$

$\boxed{V_2 = 8V}$

6.58 Determine the inductance at terminals *A*-*B* in the network in Fig. 6.58.

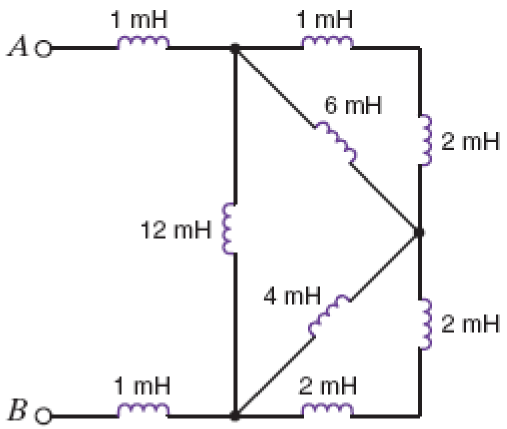
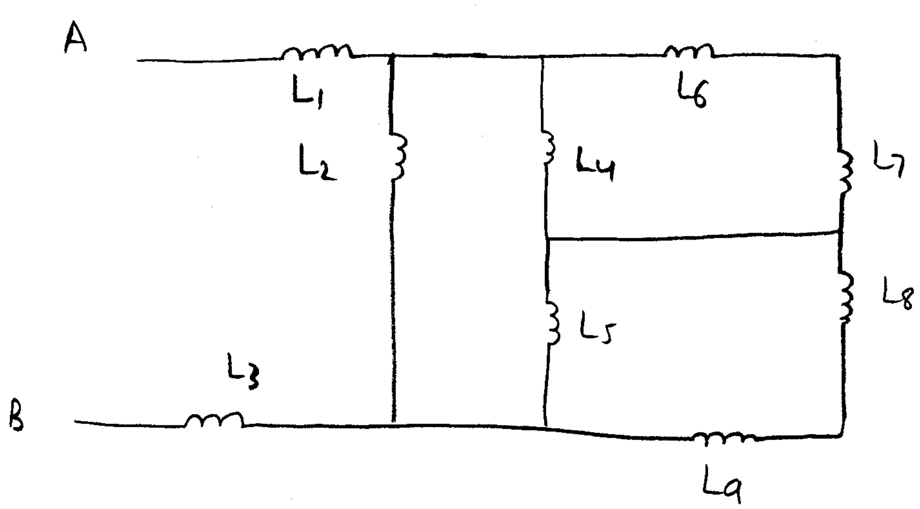


Figure P6.58

SOLUTION:



$$L_1 = L_3 = L_6 = 1mH$$

$$L_2 = 12\,mH$$

$$L_4 = 6mH \;,\; L_5 = 4mH$$

$$L_7 = L_8 = L_9 = 2mH$$

$$L_a = L_6 + L_7 = 3mH$$

$$L_b = \frac{L_4 L_a}{L_4 + L_a} = 2mH$$

$$L_c = L_8 + L_9 = 4\,mH$$

$$L_d = \frac{L_c L_5}{L_c + L_5} = 2\,mH$$

$$L_e = \frac{L_2 (L_b + L_d)}{L_2 + L_b + L_d}$$

$$L_e = 3\,mH$$

$$L_{AB} = L_1 + L_3 + L_e$$

$$L_{AB} = 5\,mH$$

6.59 Determine the inductance at terminals *A-B* in the network in Fig P6.59.

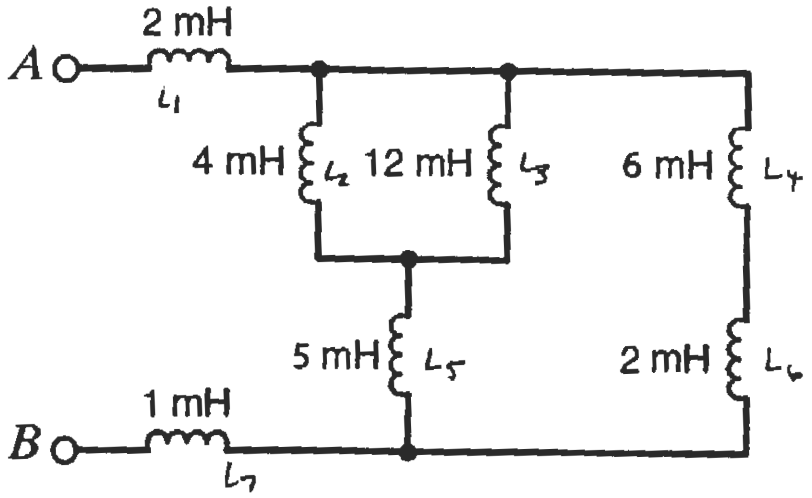
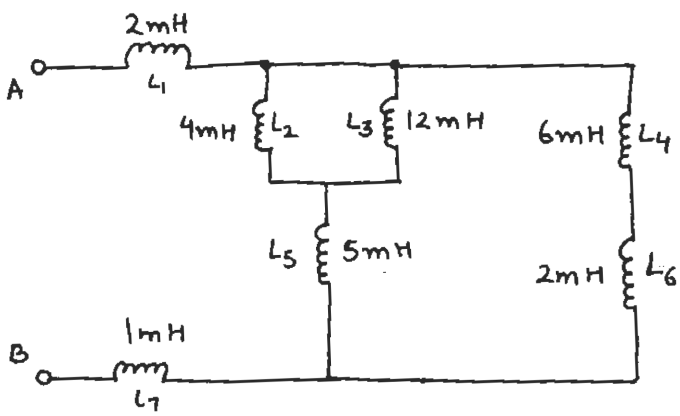


Figure P6.59

Solution: 6.59



$$L_x = L_5 + \frac{L_2 L_3}{L_2 + L_3}$$

$$= 8\text{mH}$$

$$L_Y = L_4 + L_6$$

$$= 8\text{mH}$$

$$L_{AB} = L_1 + L_7 + \frac{L_x L_y}{L_x + L_y}$$

$$\boxed{L_{AB} = 9\text{mH}}$$

6.60 Find the total inductance at the terminals of the network in Fig. P6.60.

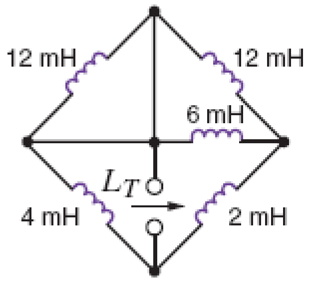
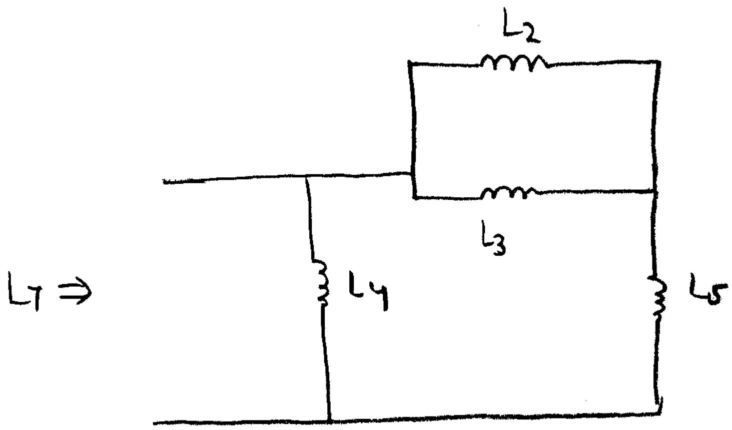


Figure P6.60

SOLUTION:

Redraw circuit:



$L_2 = 12mH$, $L_3 = 6mH$, $L_4 = 4mH$, and $L_5 = 2mH$

note: $L_1 = 12mH$ was shorted.

$$L_T = \left[(L_2 \| L_3) + L_5 \right] \| L_4$$

$$L_T = \left[(12m \| 6m) + 2m \right] \| 4m$$

$$L_T = \left[\frac{12m(6m)}{12m+6m} + 2m \right] \| 4m$$

$$L_T = 6m \parallel 4m$$

$$L_T = 2.4\,mH$$

6.61 Compute the equivalent inductance of the network in Fig. P6.61 if all inductors are 4 mH.

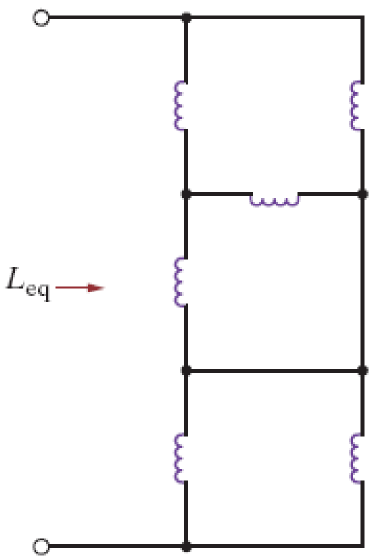
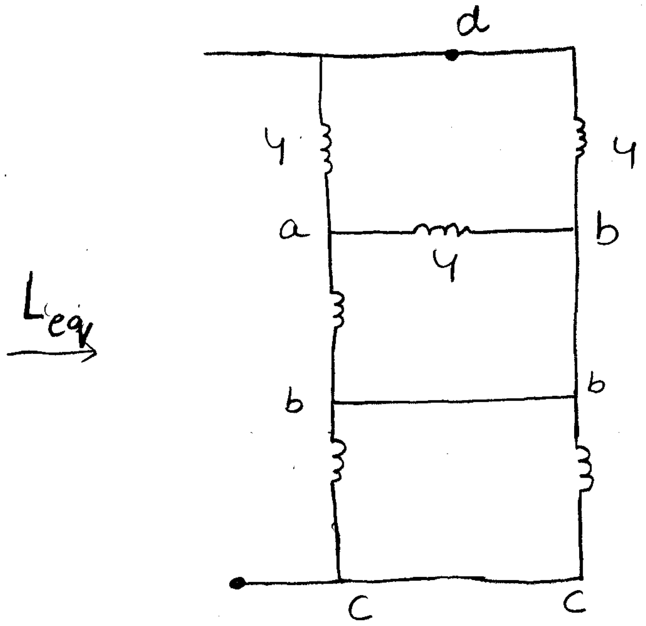
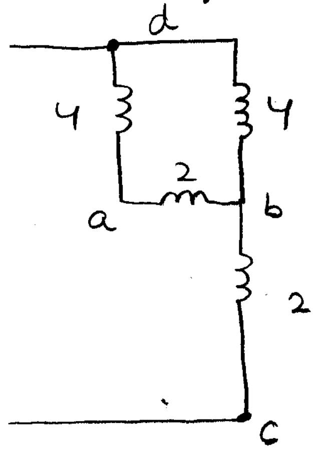


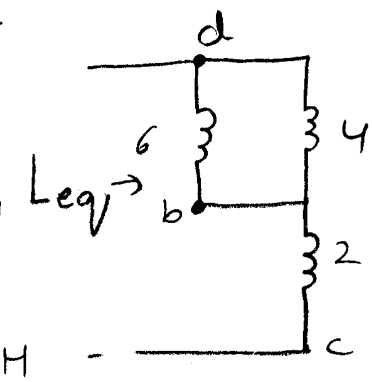
Figure P6.61

SOLUTION:



Redrawing





$$L_a = \frac{L_1 L_2}{L_1 + L_2} = 2mH$$

$$L_b = \frac{L_3 L_4}{L_3 + L_4} = 2mH$$

$$L_{eq} = [(6 \parallel 4) + 2]\ mH$$

$$L_{eq} = \frac{6(4)}{2} + 2$$

$$= 4.4\ mH$$

6.62 Find L_T in the network in Fig. P6.62 (a) with the switch open and (b) with the switch closed. All inductors are 12 mH.

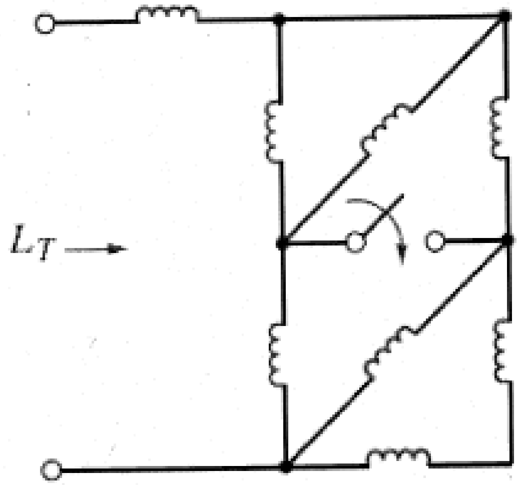
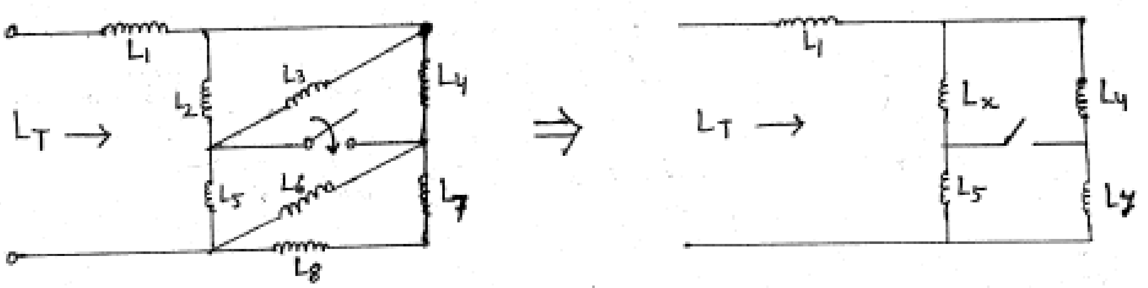


Figure P6.62

Solution: 6.62



$$L_x = \frac{L_2 L_3}{L_2 + L_3} = 6\,mH \qquad L_y = \frac{L_6(L_7 + L_8)}{L_6 + L_7 + L_8} = 8\,mH$$

(a) $$L_T = L_1 + \frac{(L_x + L_5)(L_4 + L_y)}{L_x + L_5 + L_4 + L_y} = 21.47\,mH$$

$$\boxed{L_T = 21.5\,mH}$$

(b) $$L_T = L_1 + \frac{L_x L_4}{L_x + L_4} + \frac{L_5 L_y}{L_5 + L_y} = 20.8\,mH$$

$$\boxed{L_T = 20.8\,mH}$$

6.63 Given the network shown in Fig. P6.63, find **(a)** the equivalent inductance at terminals *A-B* with terminals *C-D* short circuited, and **(b)** the equivalent inductance at terminals *C-D* with terminals A-B open circuited.

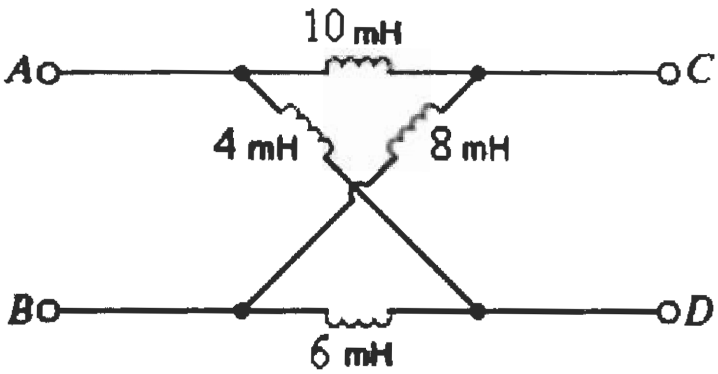
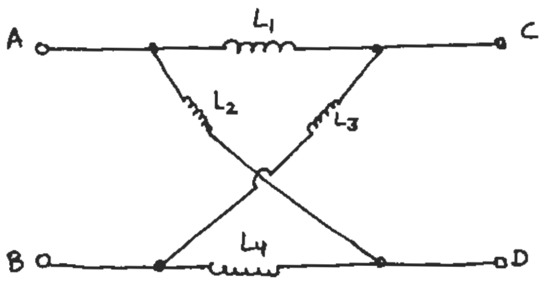
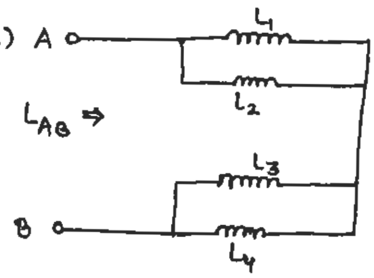


Figure P6.63

Solution: 6.63

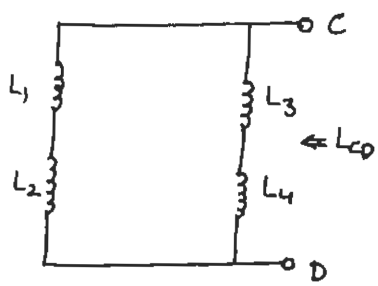


(a)



$$L_{AB} = \frac{L_1 L_2}{L_1 + L_2} + \frac{L_3 L_4}{L_3 + L_4}$$

$$\boxed{L_{AB} = 6.29 \text{ mH}}$$



$$L_{CD} = \frac{(L_1 + L_2)(L_3 + L_4)}{L_1 + L_2 + L_3 + L_4}$$

$$\boxed{L_{CD} = 7 \text{ mH}}$$

6.64 Find the value of L in the network in Fig. P6.64 so that the total inductance L_T will be 2.25 mH.

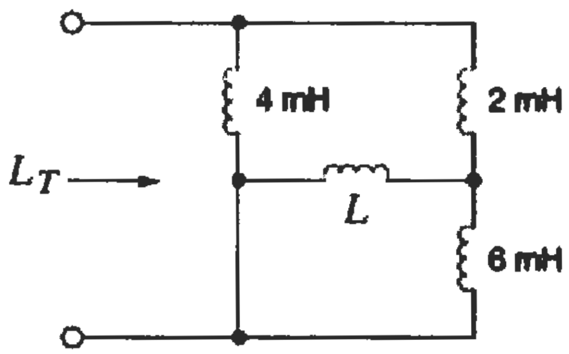
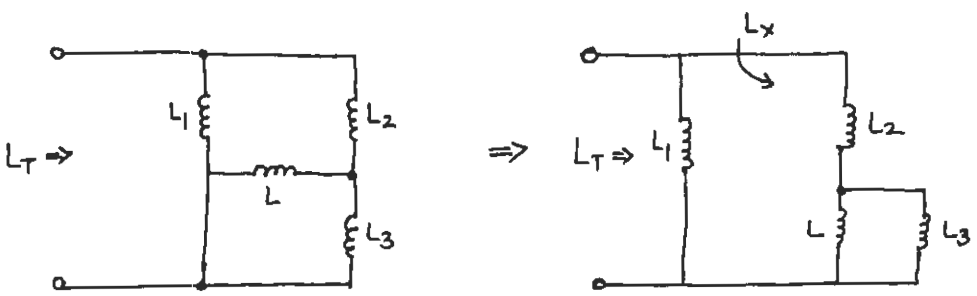


Figure P6.64

Solution: 6.64



$$L_x = L_2 + \frac{LL_3}{L+L_3} = 2 + \frac{6L}{6+L} \text{ mH}$$

$$L_T = \frac{L_1 L_x}{L_1 + L_x} = 2.25 \text{ mH} \Rightarrow \boxed{L = 6.60 \text{ mH}}$$

6.65 Find the value of L in the network in Fig. P6.65 so that the value of L_T will be 2 mH.

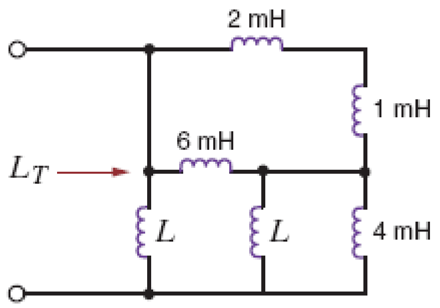
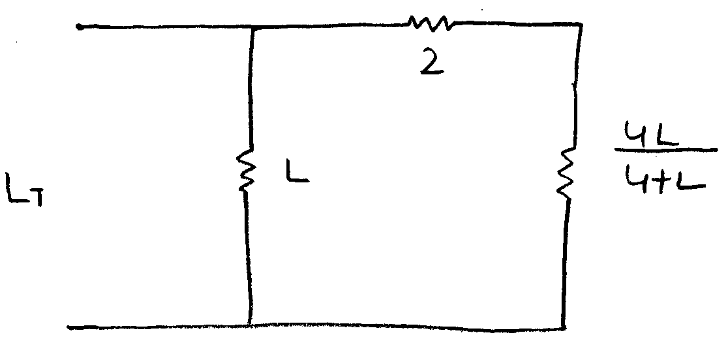


Figure P6.65

SOLUTION:



$$L_T = \left(2 + \frac{4L}{4+L}\right) \parallel L$$

$$L_T = \frac{\left(2 + \frac{4L}{4+L}\right) L}{L + 2 + \frac{4L}{4+L}}$$

$$L_T = \frac{2L + \frac{4L^2}{4+L}}{\frac{L(4+L) + 2(4+L) + 4L}{4+L}}$$

$$L_T = \frac{\dfrac{2L(4+L)+4L^2}{4+L}}{\dfrac{4L+L^2+8+2L+4L}{4+L}}$$

$$L_T = \frac{8L+2L^2+4L^2}{8L+L^2+8+2L}$$

$$L_T = \frac{6L^2+8L}{L^2+10L+8}$$

$$L_T = \frac{6L^2+8L}{L^2+10L+8}$$

$$6L^2+8L = 2L^2+20L+16$$

$$4L^2-12L-16=0$$

$$L^2-3L-4=0$$

$$(L-4)(L+1)=0$$

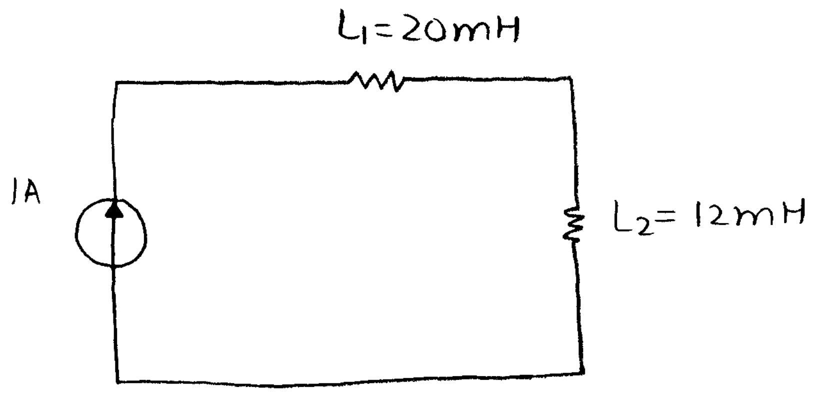
$$L=4 \quad , \quad L=-1$$

$$L=4\text{mH}$$

6.66 A 20-mH inductor and a 12-mH inductor are connected in series with a 1-A current source. Find (a) the equivalent inductance and (b) the total energy stored.

SOLUTION:

(a)



$$L_{eq} = L_1 + L_2 = 20m + 12m$$

$$L_{eq} = 32mH$$

(b)

$$W_{total} = W_1 + W_2$$

$$W_{total} = \frac{1}{2} L_1 I^2 + \frac{1}{2} L_2 I^2$$

$$W_{total} = \frac{1}{2}(20m)(1)^2 + \frac{1}{2}(12m)(1)^2$$

$$W_{total} = 16mJ$$

6.67 For the network in Fig. P6.67, $v_S(t) = 120 \cos 377t$ V. Find $v_o(t)$.

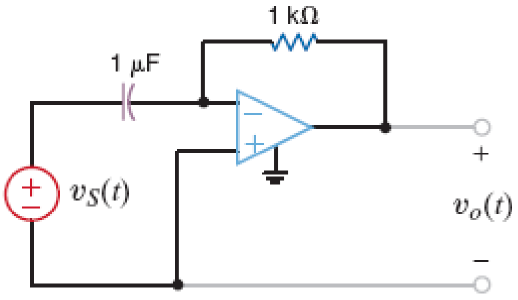
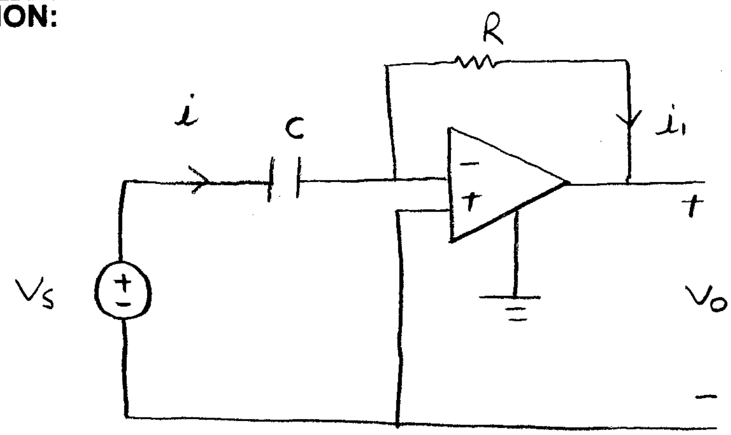


Figure P6.67

SOLUTION:



$C = 1\,\mu F$ and $R = 1\,K\Omega$

$V_S(t) = 120 \cos 377t$ V

$i = i_1$ (ideal op-amp)

$$C \frac{dV_s}{dt} = -\frac{V_o}{R}$$

$$V_o = -RC \frac{dV_s}{dt}$$

$$V_o = -(1K)(1\mu)\left[-120(377) \cos 377t\right]$$

$$V_0(t) = 45.24 \sin 377t \text{ V}$$

6.68 For the network in Fig. P6.68 choose C such that

$$v_0 = -10 \int v_S \, dt.$$

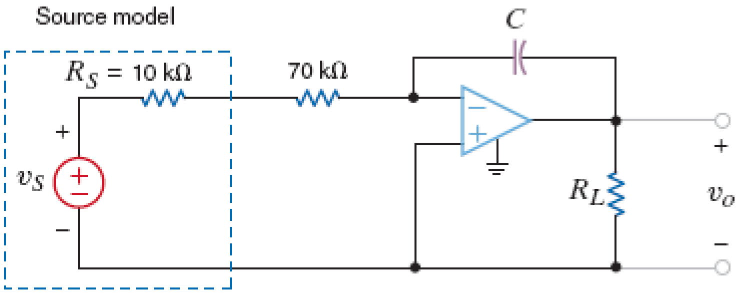
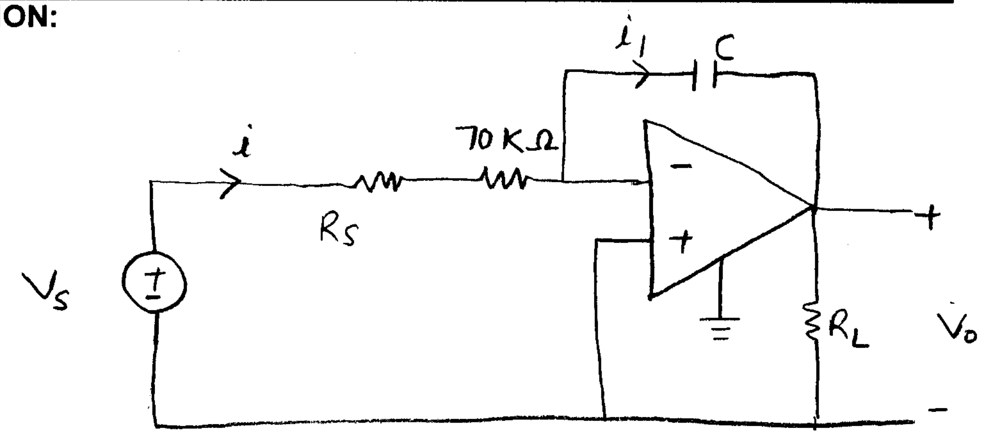


Figure P6.68

SOLUTION:



$$V_o = -10 \int V_s dt$$

$$R_S = 10 K\Omega$$

$$R_{eq} = R_S + 70K = 10K + 70K$$

$$R_{eq} = 80 K\Omega$$

$i = i_1$ (ideal op-amp)

$$\frac{V_s - 0}{R_{eq}} = \frac{-C\, dV_o}{dt}$$

$$V_o = -\frac{1}{R_{eq} C} \int V_s dt$$

$$R_{eq}C = \frac{1}{10}$$

$$C = 1.25\,\mu F$$

6.69 For the network in the Fig. P6.69 below, $v_{S_1}(t) = 80 \cos 324t$ V and $v_{S_2}(t) = 40 \cos 324t$ V. Find $v_o(t)$.

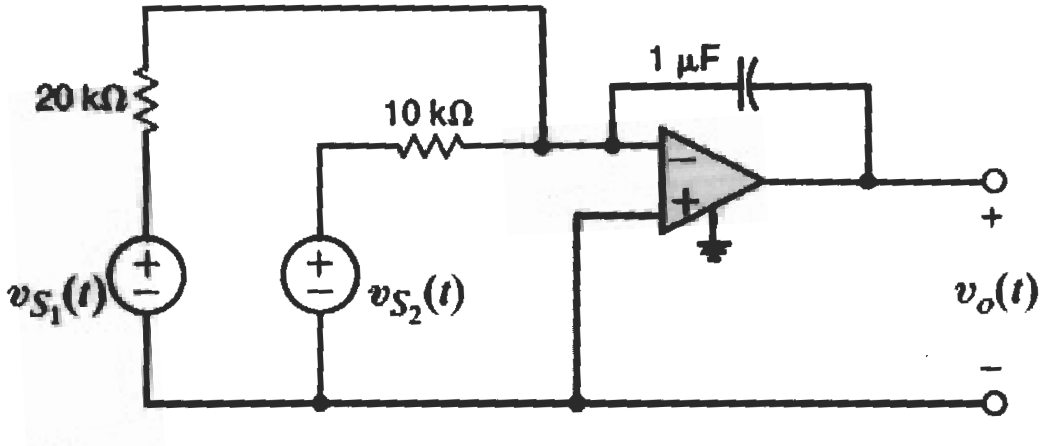
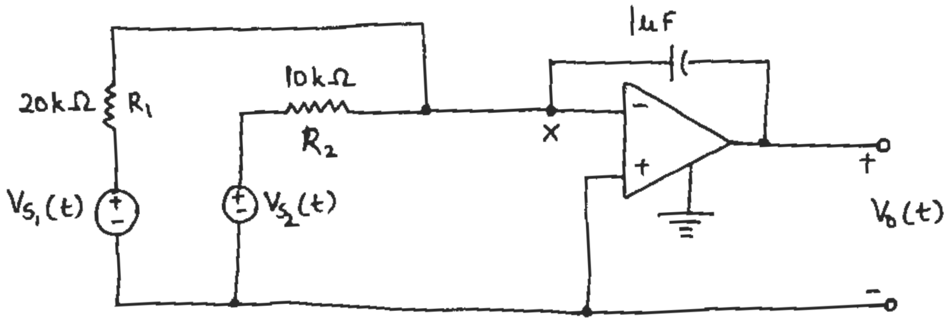


Figure P6.69

Solution: 6.69



$$\frac{V_{S_1}}{R_1} + \frac{V_{S_2}}{R_2} = -C\frac{dV_o}{dt}$$

$$\therefore\ V_o(t) = -\frac{1}{C}\int\left(\frac{V_{S_1}}{R_1} + \frac{V_{S_2}}{R_2}\right)dt$$

$$\boxed{V_o(t) = -24.7 \sin 324t \text{ V}}$$

6.70 The circuit shown in the Fig. P6.70 below is known as a "Deboo" integrator. Express the output voltage in terms of the input voltage and circuit parameters.

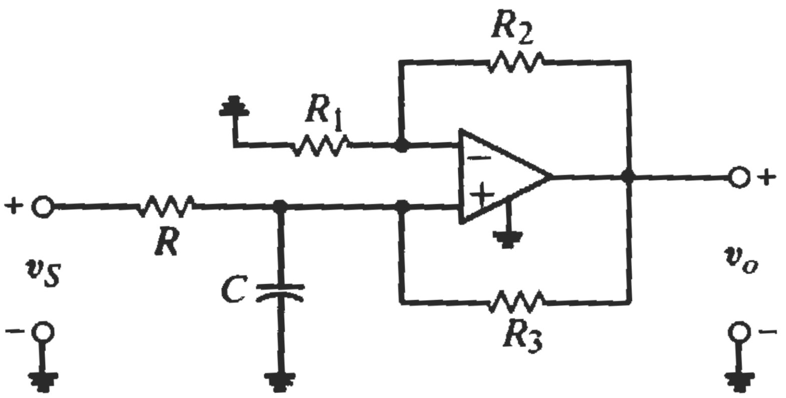
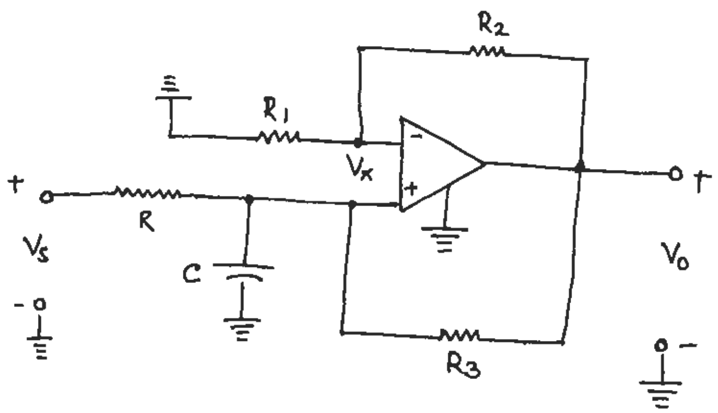


Figure P6.70

Solution: 6·70



$$V_x = V_o \frac{R_1}{R_1+R_2} = \alpha V_o$$

$$\frac{V_s - V_x}{R} = C\frac{dV_x}{dt} + \frac{V_x - V_o}{R_3}$$

$$\Rightarrow V_s = \frac{R_1 Rc}{R_1+R_2}\frac{dV_o}{dt} + \frac{V_o R_1}{(R_1+R_2)}\left(\frac{R}{R_3}+1\right) - \frac{V_o R}{R_3}$$

$$V_o = \left(\frac{R_1+R_2}{R_1}\right)\frac{1}{Rc}\int\left\{V_S(t) + \left[\frac{R}{R_3} - \frac{R_1(R+R_3)}{(R_1+R_2)R_3}\right]V_o\right\}dt$$

6.71 An integrator is required that has the following performance

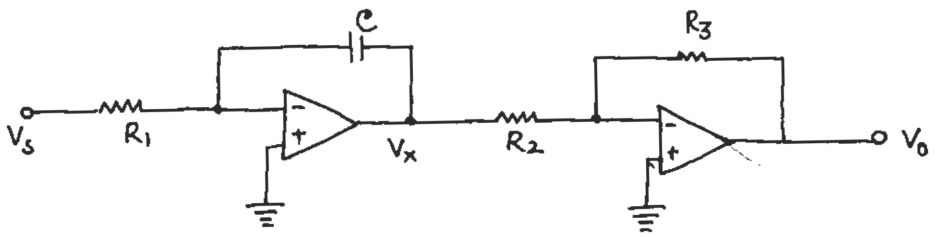
$$V_o = 10^6 \int V_S dt$$

where the capacitor values must be greater than 10 nF and the resistor values must be greater than $10\,k\Omega$.

(a) If ±20 v supplies are used, what are the maximum and minimum values of V_o?

(b) Suppose $V_S = 1$ v. What is the rate of changes of V_o?

Solution: 6.71



$$V_x = -\frac{1}{R_1 C}\int V_S\,dt \qquad V_0 = -\frac{R_3}{R_2} V_x$$

$$V_0 = \frac{R_3}{C R_1 R_2}\int V_s\,dt$$

Arbitrarily select : $C = 20\,nF$, $R_1 = 20\,k\Omega$, $R_2 = 20\,k\Omega$

$R_3 = 8\,M\Omega$

(a) V_0 cannot exceed the supplies and it is limited to $\pm 20V$

$$\boxed{V_{0\,max} = 20\,V}$$

$$\boxed{V_{0\,min} = -20\,V}$$

(b) $V_S = 1\,V$ $\qquad V_0(t) = 10^6\int dt$

$$= 10^6 t$$

$$\boxed{\frac{dV_0}{dt} = 10^6\,V/s}$$

6.72 A driverless automobile is under development. One critical issue is braking, particularly at red lights. It is decided that the braking effort should depend on distance to the light (if you're close, you better stop now) and speed (if you're going fast, you'll need more brakes). The resulting design equation is

$$\text{braking effort} = K_1\left[\frac{dx(t)}{dt}\right] + K_2x(t)$$

where x, the distance from the vehicle to the intersection, is measured by a sensor whose output is proportional to x, $v_{sense} = \alpha x$. Use superposition to show that the circuit in Fig. P6.72 can produce the braking effort signal.

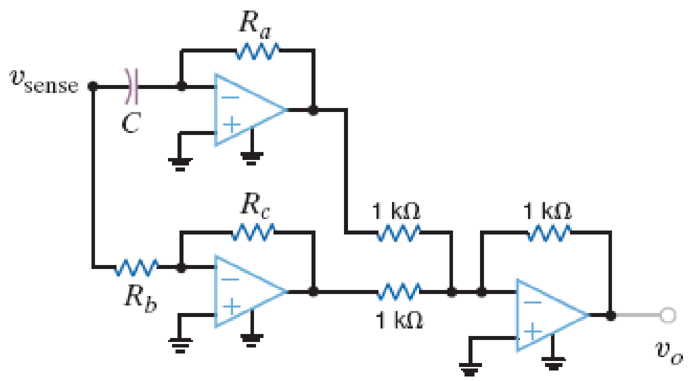
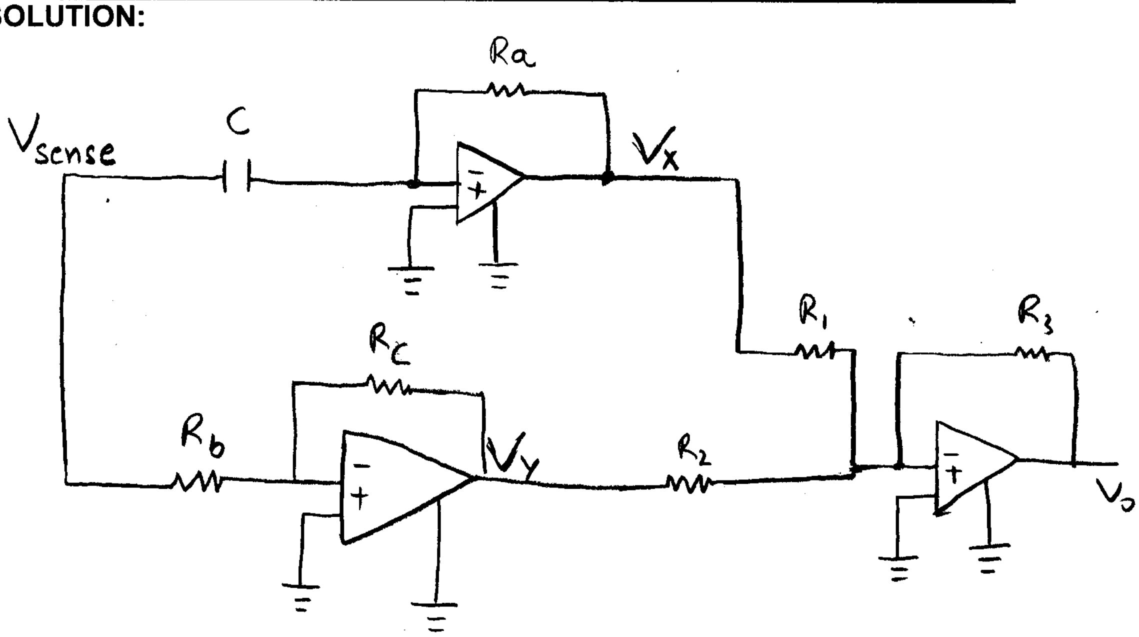


Figure P6.72

SOLUTION:



$$V_x = -R_a C \frac{dV_{sense}}{dt}$$

$$V_y = \frac{-R_c}{R_b} V_{sense}$$

$$V_o = \frac{-R_3}{R_1} V_x - \frac{R_3}{R_2} V_y$$

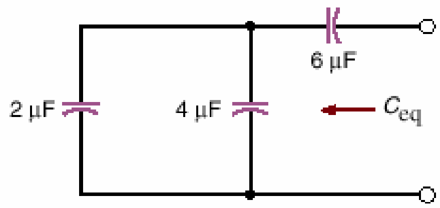
$$V_o = \alpha \frac{R_3 R_a C}{R_1} \frac{dx}{dt} + \frac{R_3}{R_2} \frac{R_c}{R_b} \alpha x$$

$$K_1 = \frac{\alpha R_3 R_a C}{R_1}$$

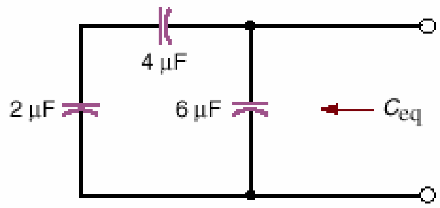
$$K_2 = \frac{R_3 R_c}{R_2 R_b}$$

6FE-1 Given three capacitors with values 2-µF, 4-µF, and 6-µF, can the capacitors be interconnected so that the combination is an equivalent 3-µF capacitor?

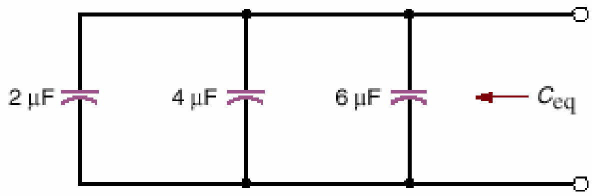
a. Yes. The capacitors should be connected as shown.



b. Yes. The capacitors should be connected as shown.



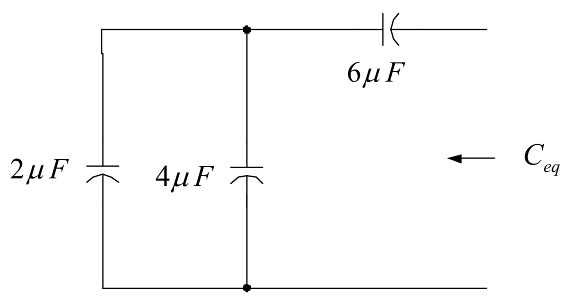
c. Yes. The capacitors should be connected as shown.



d. No. An equivalent capacitance of 3 µF is not possible with the given capacitors.

SOLUTION:

The correct answer is *a*.
Yes. The capacitors should be connected as shown.



$$C_{eq} = \frac{6\mu(6\mu)}{6\mu + 6\mu} = 3\mu F$$

6FE-2 The current pulse shown in Fig. 6PFE-2 is applied to a 1-μF capacitor. What is the energy stored in the electric field of the capacitor?

a. $w(t) = \begin{cases} 0\ J, t \le 0 \\ 10 \times 10^6 t^2 J, 0 < t \le 1\ \mu s \\ 10\ \mu J, t > 1\ \mu s \end{cases}$

b. $w(t) = \begin{cases} 0\ J, t \le 0 \\ 6 \times 10^6 t\ J, 0 < t \le 1\ \mu s \\ 6\ \mu J, t > 1\ \mu s \end{cases}$

c. $w(t) = \begin{cases} 0\ J, t \le 0 \\ 18 \times 10^6 t^2 J, 0 < t \le 1\ \mu s \\ 18\ \mu J, t > 1\ \mu s \end{cases}$

d. $w(t) = \begin{cases} 0\ J, t \le 0 \\ 30 \times 10^6 t\ J, 0 < t \le 1\ \mu s \\ 30\ \mu J, t > 1\ \mu s \end{cases}$

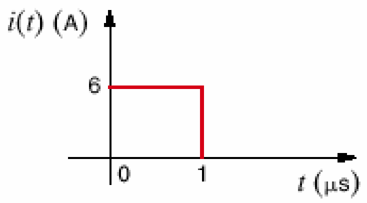


Figure 6PFE-2

SOLUTION:

The correct answer is *c*.

$$q(t) = \int i(t)\,dt$$

$$q(t) = \begin{cases} 0\ \ C,\ \ t \le 0 \\ 6t\ \ C,\ 0 < t \le 1 \mu s \\ 6\mu\ C,\ t > 1 \mu s \end{cases}$$

$$v(t) = \frac{q(t)}{C}$$

$$v(t) = \begin{cases} 0\ \ V,\ \ t \le 0 \\ 6x10^6 t\ \ V,\ 0 < t \le 1 \mu s \\ 6\ \ V,\ t > 1 \mu s \end{cases}$$

$$w(t) = \frac{1}{2} C v^2(t)$$

$$w(t) = \begin{cases} 0 J,\ \ t \le 0 \\ 18x10^6 t^2\ J,\ 0 < t \le 1 \mu s \\ 18 \mu J,\ t > 1 \mu s \end{cases}$$

6FE-3 The two capacitors shown in Fig. 6FE-3 have been connected for some time and have reached their present values. Determine the unknown capacitor C_x.

a. 20 μF

b. 30 μF

c. 10 μF

d. 90 μF

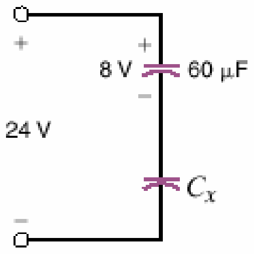


Figure 6PFE-3

SOLUTION:

The correct answer is *b*.

The voltage across the unknown capacitor C_x is (using KVL):

$$24 = 8 + V_x$$

$$V_x = 16V$$

$$q = C\,v$$

The capacitors are connected in series and the charge is the same.

$$q = 60\mu\ (8) = 480\mu\,C$$

$$C_x = \frac{q}{v} = \frac{480\mu}{16} = 30\mu\,F$$

6FE-4 What is the equivalent inductance of the network in Fig. 6PFE-4?

a. 9.5 mH b. 2.5 mH

c. 6.5 mH d. 3.5 mH

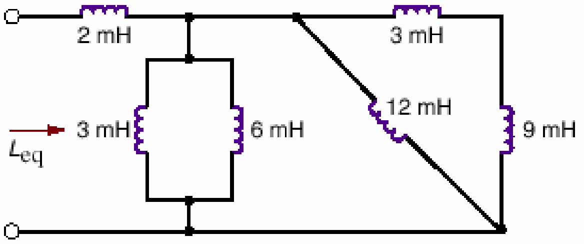
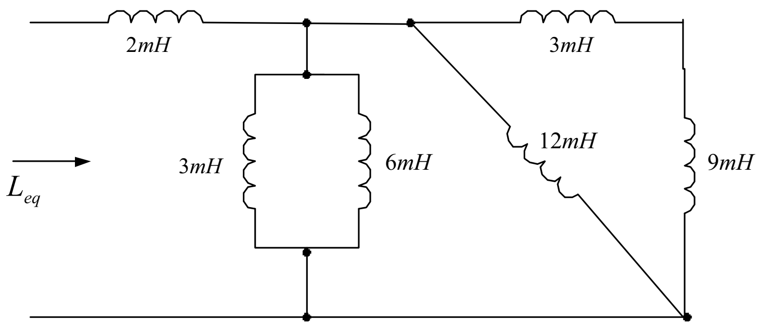


Figure 6PFE-4

SOLUTION:



The correct answer is *d*.

$$L_{eq} = [\{[(3m+9m)\|12m]\|6m\}\|3m]+2m$$

$$L_{eq} = [\{[(12m)\|12m]\|6m\}\|3m]+2m$$

$$L_{eq} = [\{6m\|6m\}\|3m]+2m$$

$$L_{eq} = [3m\|3m]+2m$$

$$L_{eq} = 1.5m+2m$$

$$L_{eq} = 3.5mH$$

6FE-5 The current source in the circuit in Fig. 6PFE-5 has the following operating characteristics:

$$i(t) = \begin{cases} 0\ A, t < 0 \\ 20te^{-2t}\ \text{A}, t > 0 \end{cases}$$

What is the voltage across the 10-mH inductor expressed as a function of time?

a. $v(t) = \begin{cases} 0\ V, t < 0 \\ 0.2e^{-2t} - 4te^{-2t}\ V, t > 0 \end{cases}$

b. $v(t) = \begin{cases} 0\ V, t < 0 \\ 2e^{-2t} + 4te^{-2t}\ V, t > 0 \end{cases}$

c. $v(t) = \begin{cases} 0\ V, t < 0 \\ -0.2te^{-2t} + 0.4e^{-2t}\ V, t > 0 \end{cases}$

d. $v(t) = \begin{cases} 0\ V, t < 0 \\ -2te^{-2t}\ V, t > 0 \end{cases}$

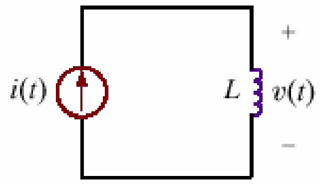


Figure 6PFE-5

SOLUTION:

The correct answer is *a*.

$$v(t) = L\frac{di(t)}{dt}$$

$$\frac{di(t)}{dt} = 20te^{-2t}(-2) + 20e^{-2t} = 20e^{-2t} - 40te^{-2t}$$

$$v(t) = 10m\left[20e^{-2t} - 40te^{-2t}\right]$$

$$v(t) = \begin{cases} 0\ V,\ t < 0 \\ 0.2e^{-2t} - 0.4te^{-2t}\ V, t > 0 \end{cases}$$

7.3

For $t = 0-$, the circuit is in steady state therefore the inductor acts as a short circuit,
The initial current through the indcutor is found as shown in Fig (a),

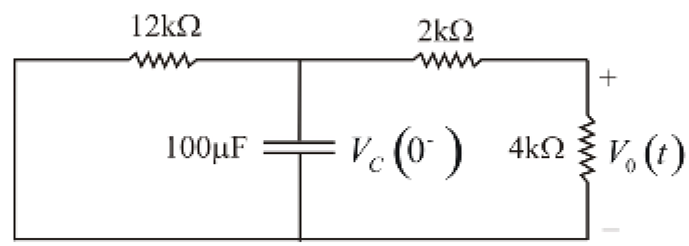
$$\therefore i_L(0-) = \frac{12}{6}$$

$$i_L(0-) = 2\text{A}$$

$$i_L(0+) = 2\text{A} \qquad (\because i_L(0+) = i_L(0-))$$

Step 1

For $t \le 0^-$ the circuit is



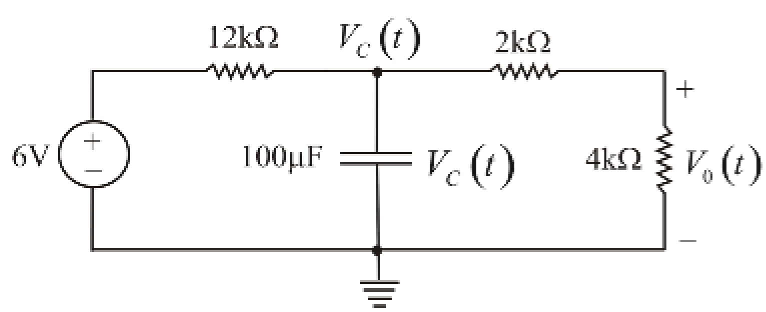
Step 2

Since there is no source

$$V_C(0^-) = 0\,\text{V}$$

$$V_0(0^-) = 0\text{V}$$

For $t \ge 0^+$, the circuit becomes



Step 3 Add/View Comments

Now writing the KCL equation at the top node,

$$\frac{V_C(t)-6}{12\text{k}} + (100\mu)\frac{dV_C(t)}{dt} + \frac{V_C(t)}{(2\text{k}+4\text{k})} = 0$$

$$(100\mu)\frac{dV_C(t)}{dt} + V_C(t)\left[\frac{1}{12\text{k}} + \frac{1}{6\text{k}}\right] = \frac{6}{12\text{k}}$$

$$\frac{dV_C(t)}{dt} + V_C(t)\left[\frac{1}{(4\text{k})(100\mu)}\right] = \frac{1}{(2\text{k})(100\mu)}$$

$$\frac{dV_C(t)}{dt} + 2.5V_C(t) = 5$$

Step 4 Add/View Comments

The solution to this equation is of the form

$$V_C(t) = \text{k}_1 + \text{k}_2 e^{-t/\tau}$$

Substituting this we have

$$\frac{-\text{k}_2}{\tau} e^{-t/\tau} + \left(\text{k}_1 + \text{k}_2 e^{-t/\tau}\right)2.5 = 5$$

Comparing on both sides

$$2.5\text{k}_1 = 5$$

$$\text{k}_1 = 2,$$

$$-\frac{1}{\tau} + 2.5 = 0$$

$$\tau = \frac{1}{2.5}$$

$$\tau = 0.4$$

 Step 5 Add/View Comments

Therefore the solution is

$$V_C(t) = 2 + k_2 e^{-t/0.4}$$

At $t = 0^-$, $V_C(0^-) = 0$

Hence $0 = 2 + k_2$

$$k_2 = -2$$

Hence $V_C(t) = 2\left(1 - e^{-2.5t}\right)$ V

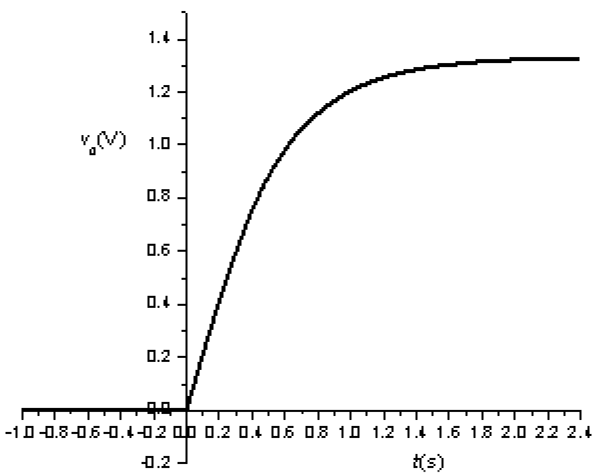
By voltage division

$$V_0(t) = V_C(t)\left[\frac{4k}{4k + 2k}\right]$$

$$= \frac{4}{6} \times 2\left(1 - e^{-2.5t}\right)$$

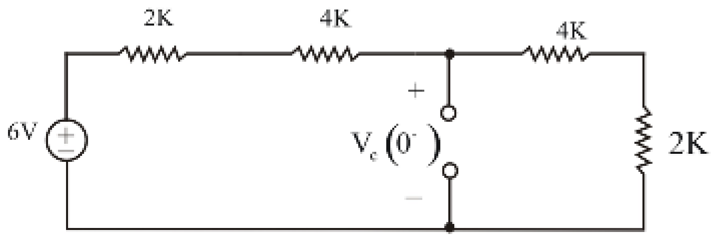
$$\boxed{V_0(t) = \frac{4}{3}\left(1 - e^{-2.5t}\right)\text{V}}$$

 Step 6 Add/View Comments



Step 1 Add/View Comments

For $t < 0^-$ the circuit is



Step 2 Add/View Comments

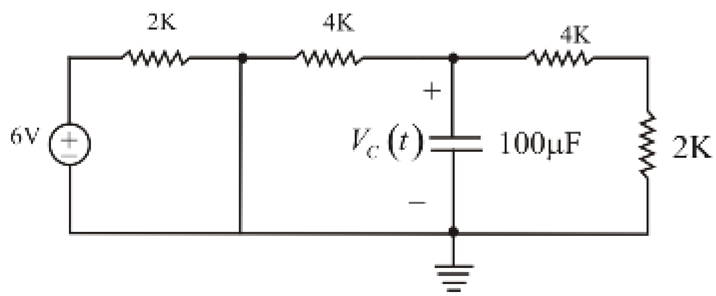
By voltage division

$[4k+2k]$

7.4

$V_C(0^-) = 3V$

For $t > 0^+$ the circuit is



Step 3 Add/View Comments

Due to the short circuit the left part is not there. So writing KCL equation at the top node,

$$(100\mu)\frac{dV_C(t)}{dt} + \frac{V_C(t)}{4k} + \frac{V_C(t)}{(4k+2k)} = 0$$

$$100\mu\frac{dV_C(t)}{dt} + V_C(t)\left[\frac{1}{4k} + \frac{1}{6k}\right] = 0$$

$$\frac{dV_C(t)}{dt} + V_C(t)\frac{1}{(2.4k)(100\mu)} = 0$$

$$\frac{dV_C(t)}{dt} + \frac{25}{6}V_C(t) = 0$$

Step 4 Add/View Comments (1)

The solution for this differential equation is of the form

$$V_C(t) = k_2 e^{-t/\tau}$$

Therefore substituting we get

$$-\frac{k_2}{\tau} e^{-t/\tau} + \frac{25}{6} k_2 e^{-t/\tau} = 0$$

Comparing we get

$$-\frac{1}{\tau} + \frac{25}{6} = 0$$

$$\tau = \frac{6}{25}$$

Step 5 Add/View Comments

7.5

Hence $V_C(t) = k_2 e^{-t/\tau}$ V

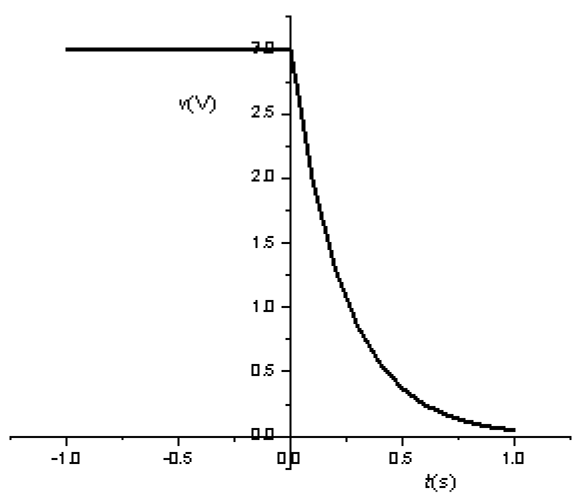
At $t = 0^-$, $V_C(0^-) = 3\text{V}$

$$3 = k_2$$

Hence the solution is of the form

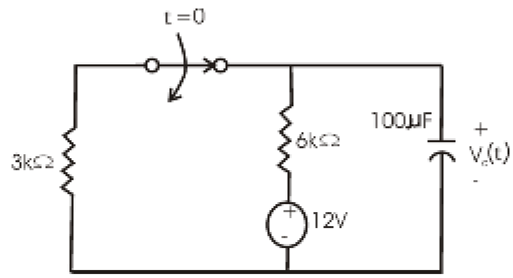
$$\boxed{V_C(t) = 3e^{-\frac{25}{6}t}\ \text{V}}$$

Step 6 Add/View Comments

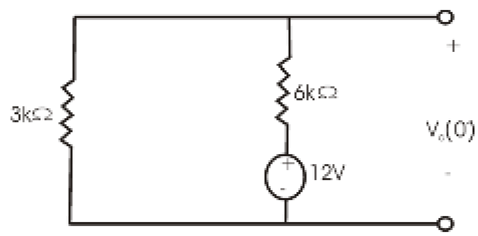


Step 1

Add/View Comments



At = 0^-



Step 2

Add/View Comments

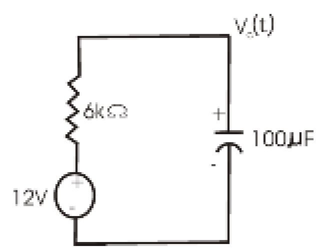
$$V_c\left(0^-\right) = \frac{12 \times 3K}{3K + 6K} = 4v$$

$$V_c\left(0^-\right) = V_c\left(0^+\right) = 4v$$

At t > 0

Step 3

Add/View Comments



Step 4

By applying nodal analysis

$$\frac{V_c - 12}{6K} + C\frac{dV_c(t)}{dt} = 0$$

$$\frac{V_c}{6K} - 2m + 100\mu\frac{dV_c(t)}{dt} = 0$$

$$\frac{dV_c(t)}{dt} + \frac{V_c(t)}{0.6} = 20 \qquad ---(1)$$

$$\frac{dx(t)}{dt} + \frac{x(t)}{T} = A \qquad --(2)$$

The solution above (2) equation is

$$x(t) = AT + K_2 e^{\frac{-t}{T}}$$

By comparing equation (1) and (2)

$$x(t) = V_c(t)$$

$$\mathrm{A} = 20$$

$$\mathrm{T} = 0.6$$

$$\Rightarrow V_c(t) = 20(0.6) + K_2 e^{\frac{-t}{0.6}}$$

$$\Rightarrow V_c(t) = K_2 e^{\frac{-t}{0.6}} + 12$$

At $t = 0^+$

$$V_x(0^+) = K_2 + 12$$

$$\Rightarrow 4 = K_2 + 12$$

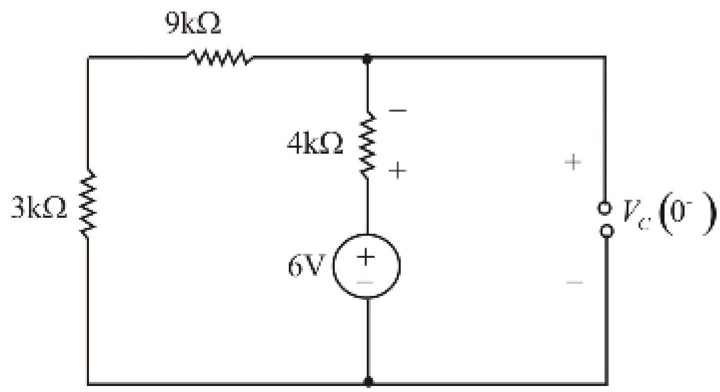
$$\Rightarrow K_2 = -8$$

$$\boxed{V(t) = 12 - 8e^{\frac{-t}{0.6}} \quad v}$$

7.6

Add/View Comments

For $t < 0^-$ the circuit is



Step 2

Add/View Comments

By voltage division voltage across $4k\Omega$,

$$V_{4k\Omega} = 6 \times \left(\frac{4k}{4k+9k+3k}\right)$$
$$= \frac{6}{4}$$
$$= \frac{3}{2}\text{V}$$
$$= 1.5\text{V}$$

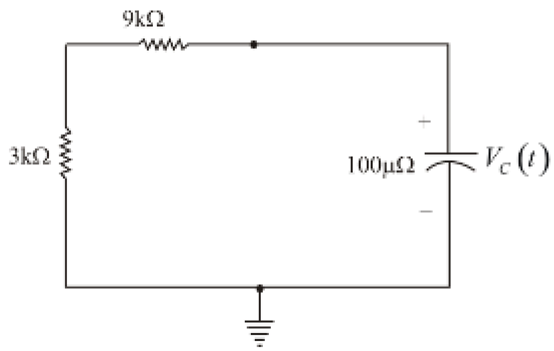
Hence $V_C(0^-) = 6 - 1.5$

$$V_C(0^-) = 4.5\text{V}$$

Step 3

Add/View Comments

At $t = 0$ the switch is open hence the circuit is



Step 4

Add/View Comments

Writing KCL equation at the top node.

$$(100\mu)\frac{dV_C(t)}{dt} + \frac{V_C(t)}{(9\text{k}+3\text{k})} = 0$$

$$\frac{dV_C(t)}{dt} + V_C(t)\left[\frac{1}{(12\text{k})(100\mu)}\right] = 0$$

$$\frac{dV_C(t)}{dt} + \frac{5}{6}V_C(t) = 0$$

Step 5

Add/View Comments

The solution for this differential equation is of the form

$V_C(t) = k_2 e^{-t/\tau}$

Substituting we get

$$-\frac{1}{\tau} k_2 e^{-t/\tau} + \frac{5}{6} k_2 e^{-t/\tau} = 0$$

Comparing we get

$$-\frac{1}{\tau} + \frac{5}{6} = 0$$

$$\tau = \frac{6}{5}$$

Step 6

Add/View Comments

Hence the solution is

$$V_C(t) = k_2 e^{-t/\left(\frac{6}{5}\right)}$$

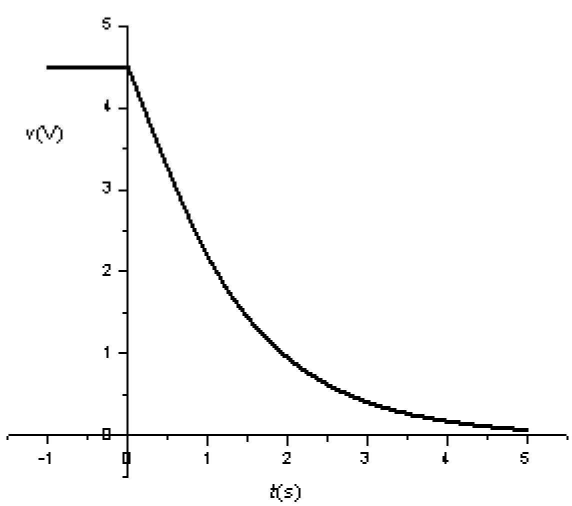
At $t = 0,\ V_C(0^-) = 4.5\text{V}$

Hence $4.5 = k_2$

Therefore $\boxed{V_C(t) = 4.5 e^{-\frac{5}{6}t}\ \text{V}}$

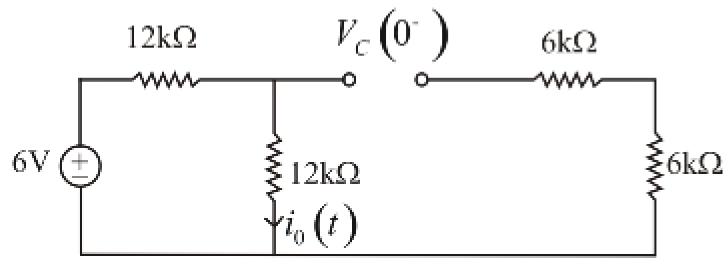
Step 7

Add/View Comments



7.7

For $t < 0^-$ the circuit is



Step 2

$$i_0(t) = \frac{6}{24\text{k}} = \frac{1}{4}\text{mA}$$

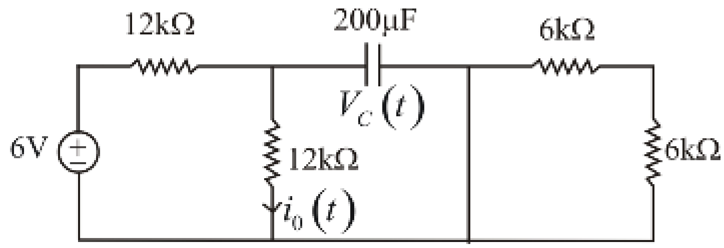
Since capacitor acts as a open circuit, no current flows through the 6kΩ,
Hence the voltage across the 12kΩ is

$$V_{12k\Omega} = (12\text{k})\left(\frac{1}{4}\right)\text{m} = 3\text{V}$$

Hence $V_C(0^-) = 3\text{V}$

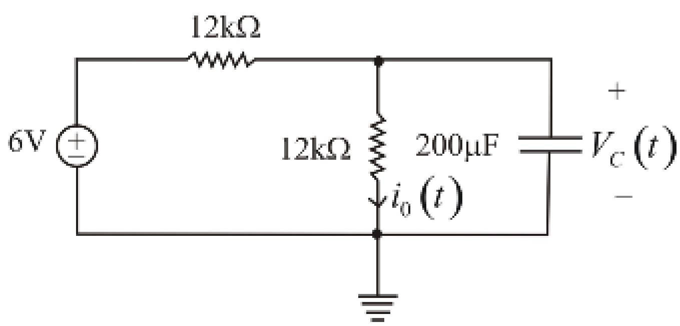
 Step 3 Add/View Comments

At $t > 0^+$ the circuit is



Step 4 Add/View Comments

Since there is a short circuit on the right side, the circuit diagram can be transformed as,



Step 5 Add/View Comments

Writing KCL equation at the top node.

$$(200\mu)\frac{dV_C(t)}{dt}+\frac{V_C(t)}{12\text{k}}+\frac{V_C(t)-6}{12\text{k}}=0$$

$$\frac{dV_C(t)}{dt}+\frac{V_C(t)}{(6\text{k})(200\mu)}=\frac{6}{(12\text{k})(200\mu)}$$

$$\frac{dV_C(t)}{dt}+\frac{5}{6}V_C(t)=2.5$$

Step 6 Add/View Comments

The solution for the differential equation is of the form

$$V_C(t)=\text{k}_1+\text{k}_2\,e^{-t/\tau}$$

Substituting we get

$$-\frac{1}{\tau}\text{k}_2e^{-t/\tau}+\frac{5}{6}\text{k}_1+\frac{5}{6}\text{k}_2\,e^{-t/\tau}=2.5$$

Comparing we get

$$\text{k}_1=\frac{6\times2.5}{5}$$

$$\text{k}_1=3$$

$$-\frac{1}{\tau}=\frac{5}{6}$$

$$\tau=\frac{6}{5}$$

 Step 7 Add/View Comments

$$V_C(t) = 3 + k_2\, e^{-t/\left(\frac{6}{5}\right)}$$

At $t = 0^-$, $V_C(0^-) = 3\text{V}$

Therefore

$$3 = 3 + k_2$$

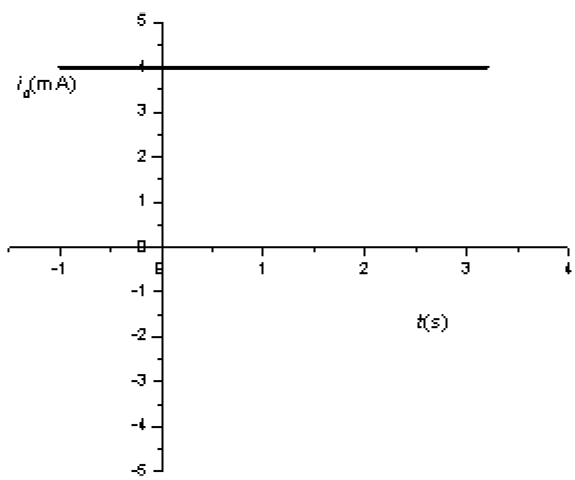
$$k_2 = 0$$

Hence $V_C(t) = 3\text{V}$

$$\text{Therefore } i_0(t) = \frac{V_C(t)}{12\text{k}} = \frac{3}{12\text{k}}$$

$$\boxed{i_0(t) = \frac{1}{4}\text{mA}}$$

 has been challenged - view comments for detail Add/View Comments (1)



7.8

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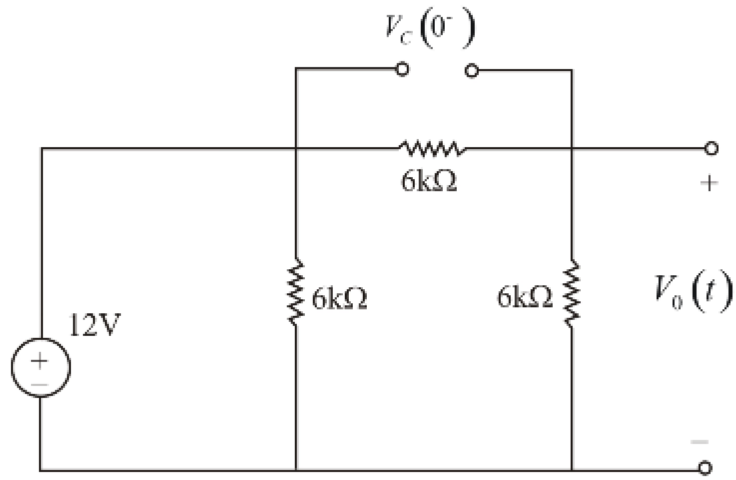
For $t < 0^-$ the circuit is



Step 2

Add/View Comments

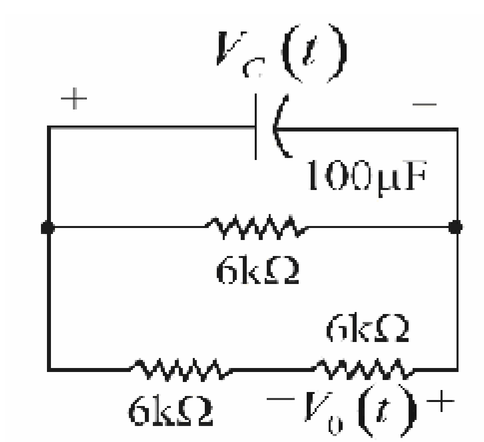
By voltage division

$$V_C(0^-) = 12 \times \frac{6k}{6k + 6k}$$

$$V_C(0^-) = 6V,$$

Add/View Comments

For $t = 0$, the switch is opened, hence the circuit is



Step 4 Add/View Comments

Writing KCL equation,

$$(100\mu)\frac{dV_c(t)}{dt}+\frac{V_c(t)}{6k}+\frac{V_c(t)}{(6k+6k)}=0$$

$$(100\mu)\frac{dV_c(t)}{dt}+\frac{V_c(t)}{4k}=0$$

$$\frac{dV_c(t)}{dt}+2.5V_c(t)=0$$

Step 5 Add/View Comments

The solution for the differential equation is of the form,

$$V_c(t)=k_2e^{-t/\tau}$$

Substituting we get

$$\frac{1}{\tau}k_2e^{-t/\tau}+2.5\,k_2e^{-t/\tau}=0$$

$$-\frac{1}{\tau}+2.5=0$$

$$\tau=\frac{1}{2.5}$$

Step 6 Add/View Comments

Hence at $t=0^-$, $V_c(0^-)=6\,\text{V}$

$$6=k_2$$

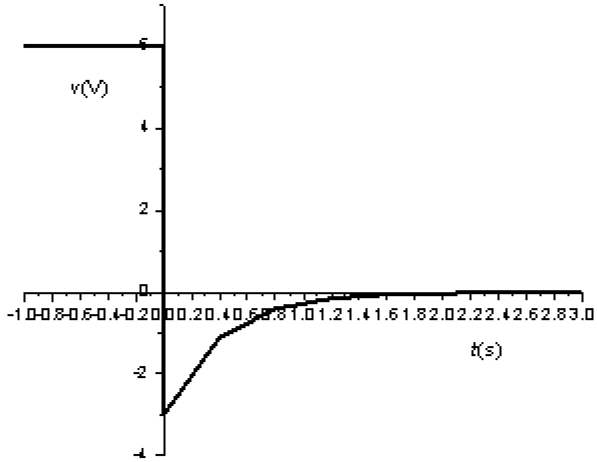
Therefore $V_c(t)=6e^{-2.5t}\,\text{V}$

Hence, $V_0(t)=-V_c(t)\left[\frac{6k}{6k+6k}\right]$

$$=-6e^{-2.5t}\left[\frac{1}{2}\right]$$

$$\boxed{V_0(t)=-3e^{-2.5t}\ \text{V}}$$

 Add/View Comments



7.9

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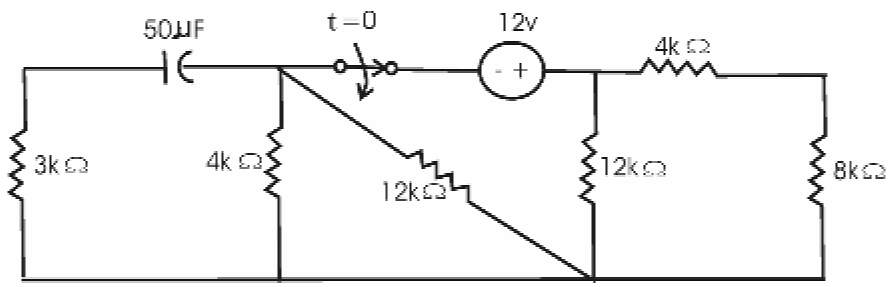
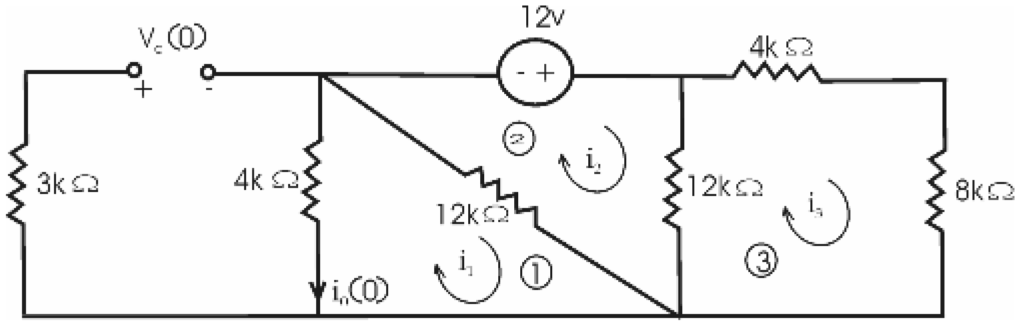


Step 2

Add/View Comments

At t = 0^-



Step 3

Add/View Comments

By applying KVL to the loop (2)

$$-12 + 12i_2 - 12i_3 + 12i_2 - 12i_1 = 0$$

$$-12i_1 + 24i_2 - 12i_3 = 12 \quad \rightarrow (1)$$

Step 4

Add/View Comments

By applying KVL to the loop (1)

$$4i_1 + 12i_1 - 12i_2 = 0$$

$$16i_1 - 12i_2 = 0 \qquad \rightarrow (2)$$

Step 5

Add/View Comments

By applying KVL to the loop (3)

$$4i_3 + 8i_3 + 12i_3 - 12i_2 = 0$$

$$\Rightarrow \qquad -12i_2 + 24i_3 = 0 \qquad \rightarrow (3)$$

Step 6

Add/View Comments

$i_1 = 1 \text{ mA},$

$i_2 = 1.333 \text{ mA},$

$i_3 = 0.667 \text{ mA}$

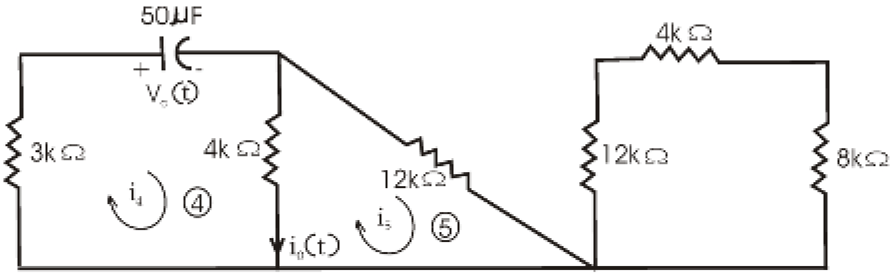
$$\Rightarrow \qquad i_0(0) = -1 \text{ mA}$$

$$V_c = (0^-) = 4\ K \times 1\text{m} = 4\text{ V}$$

$$\Rightarrow \qquad V_c = (0^-) = V_c(0^+) = 4\text{ V}$$

Step 7 Add/View Comments

at $t > 0$



Step 8 Add/View Comments

By applying KVL to the loop (1) we get

$$3i_4 + V_c(t) + 4i_4 - 4i_5 = 0$$

$$7i_4 - 4i_5 + V_c(t) = 0 \qquad \rightarrow (1)$$

Step 9 Add/View Comments

By applying KVL to the loop (2) we get

$$12i_5 + 4i_5 - 4i_4 = 0$$

$$-4i_4 + 16i_5 = 0$$

$$4i_4 = 16i_5$$

$$\Rightarrow i_5 = \frac{4}{16} i_4 \qquad \rightarrow (2)$$

Step 10

Add/View Comments

By substituting equation (2) in equation (1)

$$(7k)i_4 - (4k)\left(\frac{4}{16}\right)i_4 + V_c(t) = 0$$

$$(6k)i_4 + V_c(t) = 0 \qquad \rightarrow (3)$$

But $\quad i_4 = 50\mu\dfrac{dV_c(t)}{dt}$

$$\Rightarrow 6\text{K} \times 50\mu\frac{dV_c(t)}{dt} + V_c(t) = 0$$

$$\Rightarrow \qquad \frac{dV_c(t)}{dt} + \frac{V_c(t)}{0.3} = 0$$

$$\Rightarrow \qquad V_c(t) = K_2\, e^{\frac{-t}{0.3}} \text{ Volt}$$

Step 11

Add/View Comments

At $t = 0^+$

$$V_c(0^+) = K_2$$

$$K_2 = 4$$

$$\Rightarrow \qquad V_c(t) = 4\, e^{\frac{-t}{0.3}} \text{ volt}$$

Step 12

$$i_o(t) = i_1 - i_2$$

and $\quad i_1 = 50\mu \dfrac{d}{dt}\left(4\, e^{\frac{-t}{0.3}}\right) \qquad \because \quad i_1 = C\dfrac{dV_c}{dt}$

$$\Rightarrow \quad i_1 = 50\mu \times 4\left(-\frac{1}{0.3}\right)e^{\frac{-t}{0.3}}$$

$$\Rightarrow \quad i_1 = -0.666\, e^{\frac{-t}{0.3}}\ \text{mA}$$

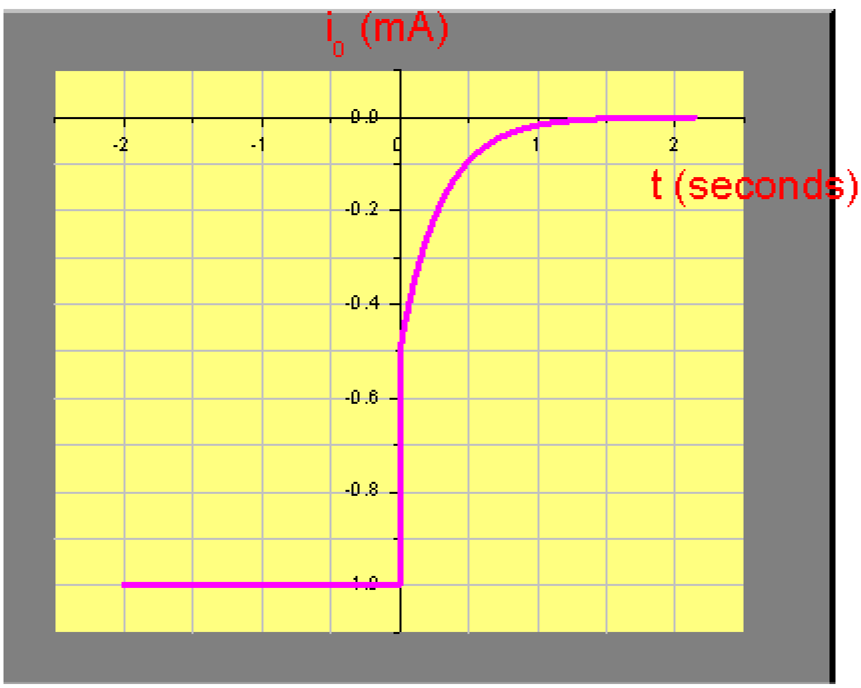
$$i_2 = \frac{4}{16}\times\left(-0.666\ e^{\frac{-t}{0.3}}\right)$$

$$i_2 = -0.1667\ e^{\frac{-t}{0.3}}\ \text{mA}$$

$$\Rightarrow \quad i_0(t) = \left(-0.666\ e^{\frac{-t}{0.3}} + 0.1667\ e^{\frac{-t}{0.3}}\right)\text{mA}$$

for $t > 0 \quad \Rightarrow \quad \boxed{i_0(t) = -0.5\, e^{\frac{-t}{0.3}}\ \text{mA}}$

Step 13



7.10

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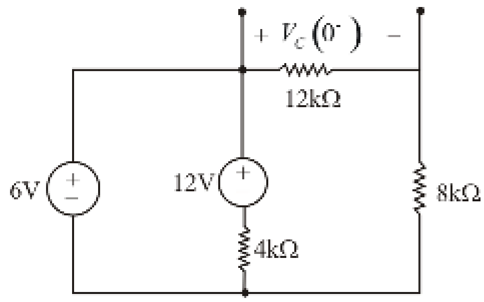
For $t = 0^-$, the circuit is



Step 2

Add/View Comments (2)

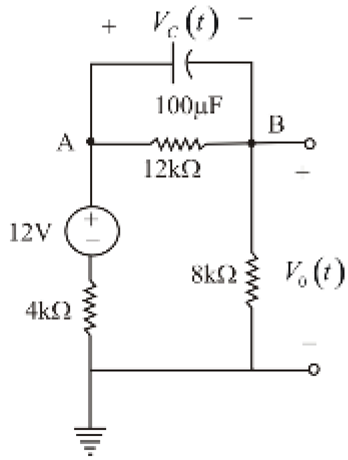
By voltage division

$$V_C(0^-) = 6\left(\frac{12\text{k}}{12\text{k}+8\text{k}}\right)$$

$$V_C(0^-) = \frac{18}{5}\ \text{V}$$

Step 3 Add/View Comments

The circuit for $t > 0$ is



Step 4 Add/View Comments

Writing KCL equation at node A.

$$(100\mu)\frac{dV_C(t)}{dt} + \frac{V_C(t)}{12\text{k}} + \frac{V_C(t)-12}{12\text{k}} = 0$$

$$\frac{dV_C(t)}{dt} + \frac{V_C(t)}{100\mu}\left[\frac{1}{12\text{k}} + \frac{1}{12\text{k}}\right] - \frac{12}{(12\text{k})(100\mu)} = 0$$

$$\frac{dV_C(t)}{dt} + V_C(t)\left(\frac{10}{6}\right) - 10 = 0$$

Step 5 Add/View Comments

The solution for this differential equation is of the form $V_C(t) = \text{k}_1 + k_2\, e^{-t/\tau}$

Substituting this we get,

$$-\frac{1}{\tau}\, k_2 e^{-\frac{t}{\tau}} + \frac{10}{6} k_1 + \frac{10}{6} k_2 e^{-\frac{t}{\tau}} - 10 = 0$$

Comparing we get

$$\frac{10}{6} k_1 = 10$$

$$k_1 = 6$$

$$-\frac{1}{\tau} + \frac{10}{6} = 0$$

$$\tau = \frac{6}{10} s$$

Hence the solution is,

$$V_C(t) = 6 + k_2 e^{-\frac{10}{6}t} \text{ V}$$

From initial conditions at $t = 0^-$

$$V_C(0^-) = V_C(0^+) = \frac{18}{5} \text{ V}$$

$$\frac{18}{5} = 6 + k_2$$

$$k_2 = \frac{18}{5} - 6$$

$$= \frac{18-30}{5}$$

$$k_2 = \frac{-12}{5}$$

Therefore the solution is

$$V_C(t) = 6 - \frac{12}{5} e^{-\frac{10}{6}t} \text{ V}$$

Hence: $V_0(t) = -\left(V_C(t) - 12\right)\left[\frac{8k}{8k+4k}\right]$

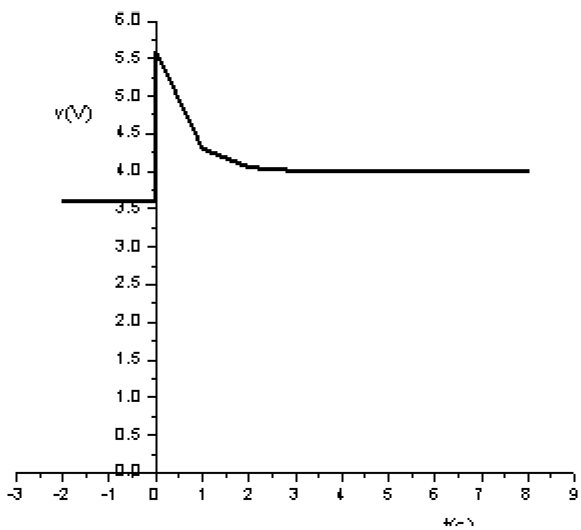
$$= -\left[6 - \frac{12}{5}e^{-\frac{10}{6}t} - 12\right]\left[\frac{2}{3}\right]$$

$$= \left[6 + \frac{12}{5}e^{-\frac{10}{6}t}\right]\left[\frac{2}{3}\right]$$

$$\boxed{V_0(t) = 4 + 1.6e^{-\frac{10}{6}t} \text{ V}}$$

Step 8

Add/View Comments

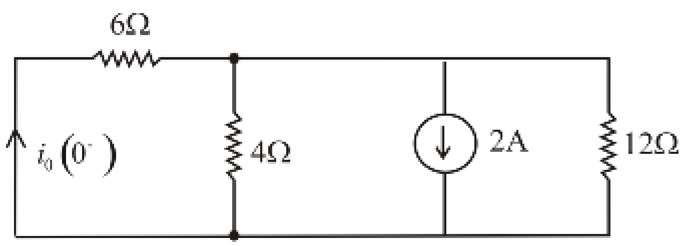


7.11

Step 1

Add/View Comments

For $t < 0^-$, the circuit is



Step 2 Add/View Comments

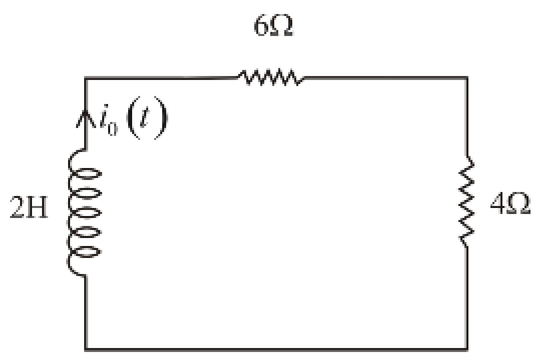
By current division

$$i_0\left(0^-\right) = 2\times\frac{(4\parallel 12)}{(6+[4\parallel 12])}$$

$$= 2\times\frac{3}{6+3}$$

$$i_0\left(0^-\right) = \frac{2}{3}\text{A}$$

For $t > 0^+$, the circuit is



Step 3 Add/View Comments

Writing KVL equation across the loop

$$2\frac{d}{dt}i_0(t) + (6+4)i_0(t) = 0$$

$$\frac{d}{dt}i_0(t) + 5i_0(t) = 0$$

The solution for this differential equation is of the form

$$i_0(t) = k_2 e^{-t/\tau}$$

Substituting

$$-\frac{1}{\tau}k_2 e^{-t/\tau} + 5k_2 e^{-\frac{t}{\tau}} = 0$$

Comparing

$$-\frac{1}{\tau} + 5 = 0$$

$$\tau = \frac{1}{5}$$

Add/View Comments

Hence the solution is

$$i_0(t) = k_2 e^{-t/\left(\frac{1}{5}\right)}$$

at $t = 0^-$, $i_0(0^-) = \dfrac{2}{3}\,\text{A}$

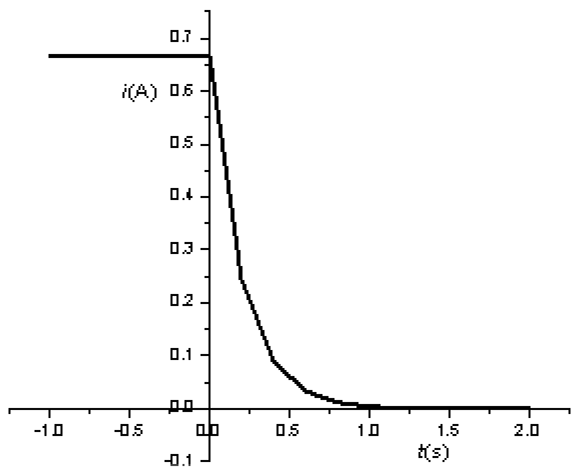
$$\frac{2}{3} = k_2$$

Hence the solution is

$$\boxed{i_0(t) = \frac{2}{3} e^{-5t}\ \text{A}}$$

Step 5

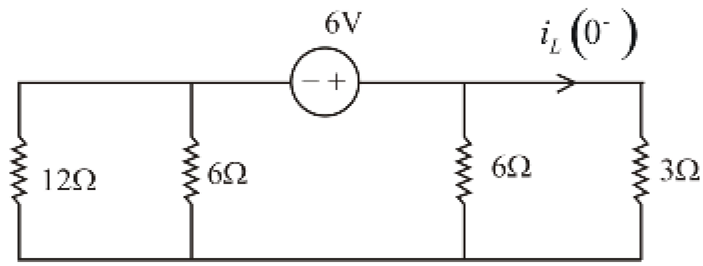
Add/View Comments



7.12

Step 1 Add/View Comments

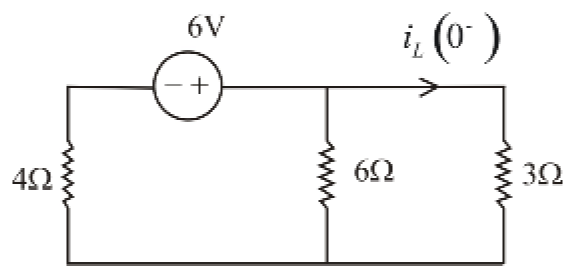
For $t < 0^-$, the circuit is



Step 2 Add/View Comments

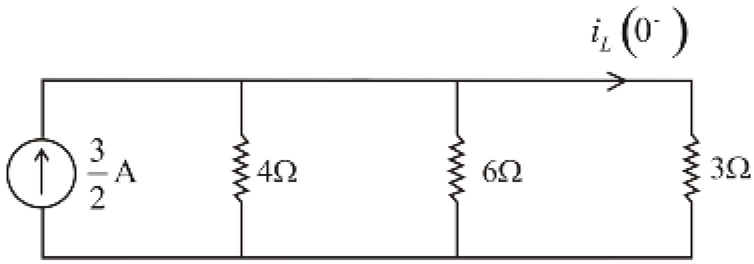
The resistors 12Ω, 6Ω are in parallel

$$R_{eq} = \frac{12 \times 6}{12+6}$$
$$= 4\Omega$$



Step 3 Add/View Comments

By source transformation technique



Step 4 Add/View Comments

By current division we get

$$i_L(0^-) = \frac{3}{2}\left[\frac{4\|6}{3+(4\|6)}\right]$$

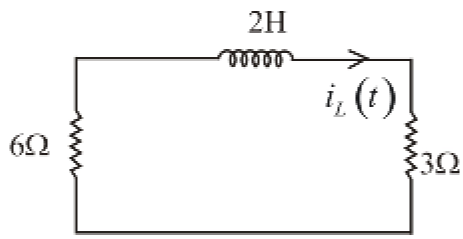
$$= \frac{3}{2}\left[\frac{\frac{12}{5}}{3+\frac{12}{5}}\right]$$

$$= \frac{3}{2}\times\frac{12}{27}$$

$$i_L(0^-) = \frac{2}{3}\text{A}$$

Step 5 Add/View Comments

For $t > 0^+$ the circuit is,



Step 6 Add/View Comments

Writing KVL equation around the loop

$$2\frac{d}{dt}i_L(t) + (6+3)\, i_L(t) = 0$$

$$\frac{d}{dt}i_L(t) + \frac{9}{2}\, i_L(t) = 0$$

The solution for this differential equation is of the form

$$i_L(t) = k_2 e^{-t/\tau}$$

Step 7 Add/View Comments

Substituting we get

$$-\frac{1}{\tau}k_2 e^{-t/\tau} + \frac{9}{2}k_2 e^{-t/\tau} = 0$$

$$-\frac{1}{\tau} + \frac{9}{2} = 0$$

$$\tau = \frac{2}{9}$$

Therefore the solution is

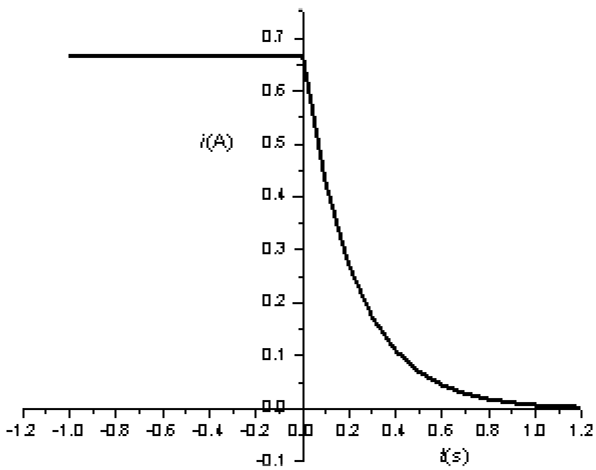
$$i_L(t) = k_2 e^{-t/\left(\frac{2}{9}\right)}$$

$$\text{at } t = 0^-,\ i_L(0^-) = \frac{2}{3}\text{A}$$

$$\frac{2}{3} = k_2$$

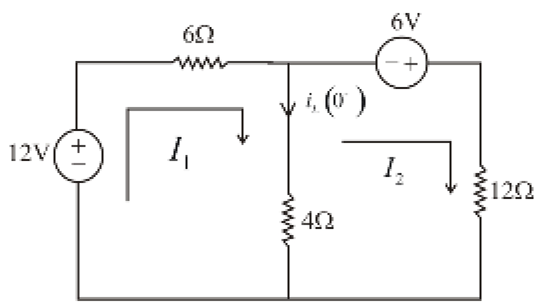
Therefore the solution is

$$\boxed{i_L(t) = \frac{2}{3}e^{-\frac{9}{2}t}\ \text{A}}$$



7.13

For $t < 0^-$, the circuit is,



Step 2

By mesh analysis

$$-12 + 6I_1 + 4(I_1 - I_2) = 0$$

$$-6 + 12I_2 + 4(I_2 - I_1) = 0$$

$$10I_1 - 4I_2 - 12 = 0 \quad \dots\dots\dots\dots\dots\dots \text{(i)}$$

$$-4I_1 + 16I_2 - 6 = 0 \quad \dots\dots\dots\dots\dots\dots \text{(ii)}$$

Solving equations (i) and (ii) we get

$$I_1 = \frac{3}{2}\text{A}$$

$$I_2 = \frac{3}{4}\text{A}$$

Step 3 Add/View Comments

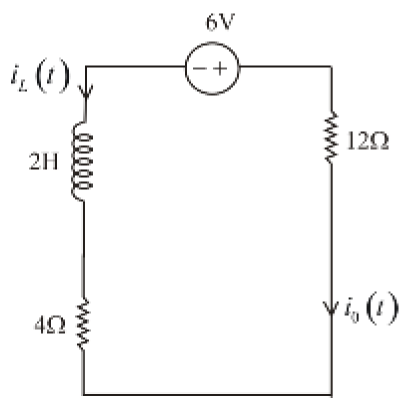
Hence $I_L(0^-) = I_1 - I_2$

$$= \frac{3}{2} - \frac{3}{4}$$

$$I_L(0^-) = \frac{3}{4}\text{A}$$

Step 4 Add/View Comments

For $t = 0$, the circuit is



Step 5 Add/View Comments

$$6 + 2\frac{d}{dt}i_L(t) + (4+12)\,i_L(t) = 0$$

$$\frac{d}{dt}i_L(t) + 8i_L(t) = -3$$

The solution for this differential equation is of the form

$$i_L(t) = k_1 + k_2 e^{-t/\tau}$$

Substituting we get

$$-\frac{1}{\tau}k_2 e^{-t/\tau} + 8k_1 + 8k_2 e^{-t/\tau} = -3$$

Step 6 Add/View Comments

Comparing

$$8k_1 = -3$$

$$k_1 = -\frac{3}{8}$$

$$-\frac{1}{\tau} + 8 = 0$$

$$\tau = \frac{1}{8}$$

Step 7 Add/View Comments

The solution is

$$i_L(t) = -\frac{3}{8} + k_2 e^{-t/\left(\frac{1}{8}\right)}$$

at $t = 0^-$ $\quad i_L(0^-) = \frac{3}{4}$

$$\frac{3}{4} = \frac{-3}{8} + k_2$$

$$k_2 = \frac{3}{4} + \frac{3}{8}$$

$$k_2 = \frac{9}{8}$$

Add/View Comments

$$i_L(t) = -\frac{3}{8} + \frac{9}{8}e^{-8t}\ \text{A}$$

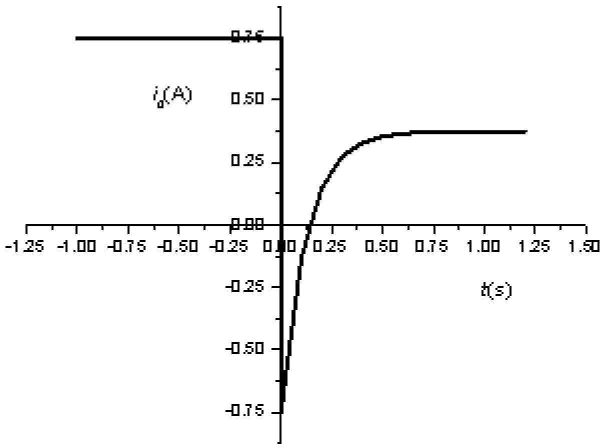
From the circuit

$$i_0(t) = -i_L(t)$$

$$\boxed{i_0(t) = \frac{3}{8} - \frac{9}{8}e^{-8t}\ \text{A}}$$

Step 9

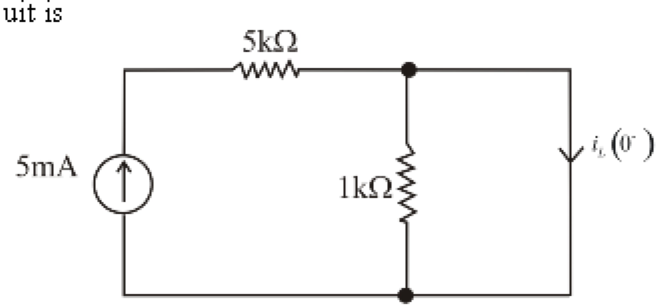
Add/View Comments



7.14

Add/View Comments

For $t = 0^-$, the circuit is

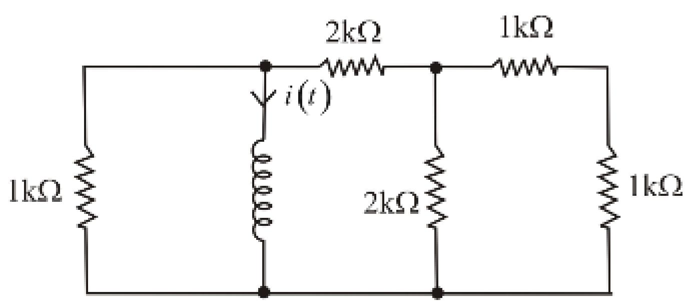


Step 2 Add/View Comments

Since inductor acts as a short circuit for a steady state, no current flows through $1\text{k}\Omega$ and towards the right part

Hence $i_L(0^-) = 5\text{mA}$

For $t > 0$, the circuit is

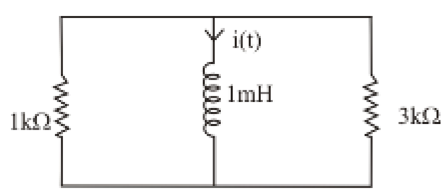


 Add/View Comments

Reducing the network from the right side

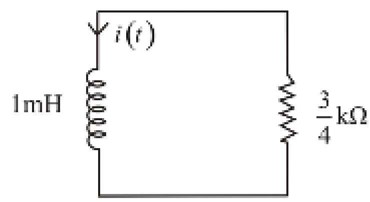
$$\begin{aligned} R_{eq} &= \left[(1\text{k}+1\text{k}) \,||\, 2\text{k}\right] + 2\text{k} \\ &= \left[2\text{k}||2\text{k}\right] + 2\text{k} \\ &= 1\text{k} + 2\text{k} \\ &= 3\text{k}\Omega \end{aligned}$$

Step 4 Add/View Comments



 Step 5 Add/View Comments

$$\text{Now } R_{eq} = \frac{1\text{k} \times 3\text{k}}{1\text{k} + 3\text{k}} = \frac{3}{4}\,\text{k}\Omega$$



 Step 6 Add/View Comments

Writing KVL equation across the loop

$$1\text{m}\ \frac{d}{dt}i(t) + i(t)\,\frac{3}{4}\text{k} = 0$$

$$\frac{d}{dt}i(t) + i(t)\frac{3}{4}\text{M} = 0$$

The solution for this differential equation is of the form

$$i(t) = k_2\, e^{-t/\tau}$$

Substituting we get

$$-\frac{1}{\tau}k_2\, e^{-t/\tau} + \frac{3}{4}\,\text{M}\ k_2 e^{-\frac{1}{\tau}} = 0$$

$$-\frac{1}{\tau} + \frac{3}{4}\,\text{M} = 0$$

$$\tau = \frac{4}{3}\,\mu\text{s}$$

 Step 7 Add/View Comments

Hence $i(t) = K_2 e^{-t/\left(\frac{4}{3}\mu s\right)}$ A

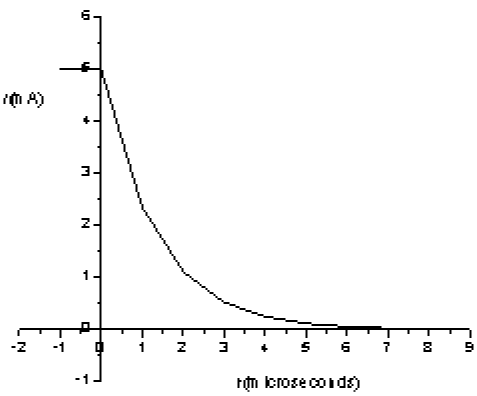
Using initial conditions $i_L(0^-) = i_L(0^+) = 5\text{m A}$

$5\text{m} = k_2$

Therefore

$$\boxed{i(t) = 5e^{-t/\left(\frac{4}{3}\mu\right)}\ \text{mA}}$$

Step 8 Add/View Comments



7.15

Add/View Comments

The given circuit is,

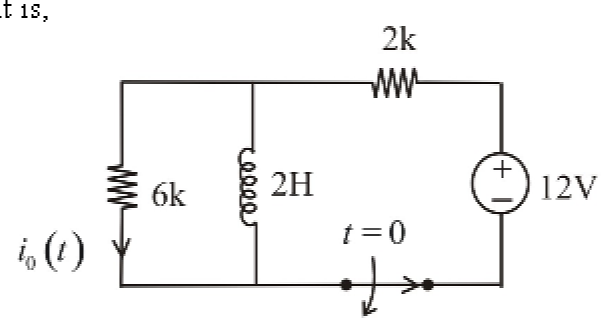


Fig (a)

Step 1: $i_0(t)$ is of the form $K_1 + K_2 e^{\frac{-t}{\tau}}$.

Step 2

Add/View Comments

Step 2: At $t = 0-$, circuit is as shown is Fig (b), the circuit is in steady state prior to time $t = 0$ therefore the inductor acts as short circuit,

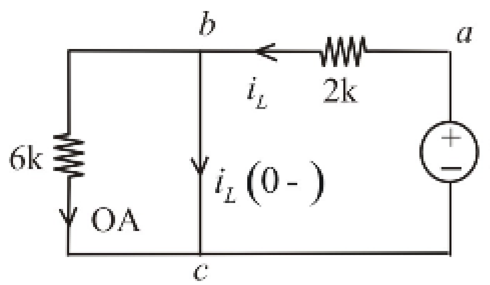


Fig (b)

Add/View Comments

The initial current through the inductor is calculated from the above circuit as,

$\because V_{bc} = 0\text{V}$, Therefore current in $6\text{k}\Omega$ is 0A

$$\therefore i_L(0-) = \frac{12}{2\text{k}}$$

$$i_L(0-) = 6 \text{ mA}$$

Step 4 Add/View Comments

Step 3: Fig (c) is the new circuit valid only at $t = 0+$,

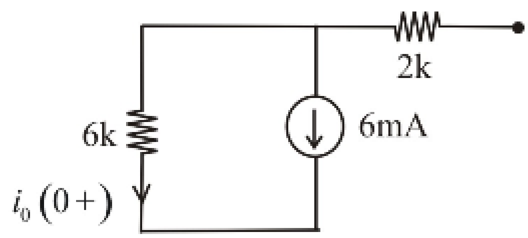


Fig (c)

Step 5 Add/View Comments

The value of the current source that replaces the inductor is,

$i_L(0-) = i_L(0+)$

$i_L(0+) = 6\text{mA}$

Hence, $i_0(0+) = -6\text{mA}$

Step 6 Add/View Comments

Step 4: The equivalent circuit, valid for $t > 5\tau$, is shown in Fig (d)

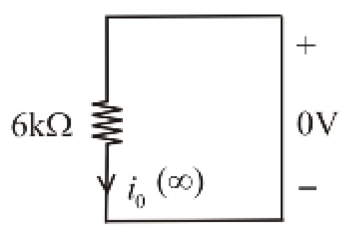


Fig (d)

$\therefore i_0(\infty) = 0 \text{ mA}$

Step 7 Add/View Comments

Step 5: The Thevenin equivalent resistance R_{Th} as seen into the open circuit terminals of the inductor,

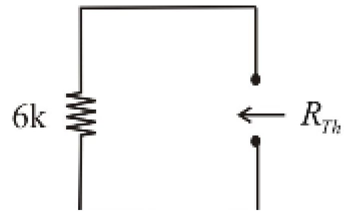


Fig (e)

7.16

Step 8 Add/View Comments

Therefore the time constant is,

$$\tau = \frac{2}{6k}$$

$$\tau = \frac{1}{3}\text{ms}$$

Step 9 Add/View Comments

Step 6: $K_1 = i_0(\infty) = 0$

$$K_2 = i_0(0+) - i_0(\infty)$$

$$K_2 = -6\text{mA}$$

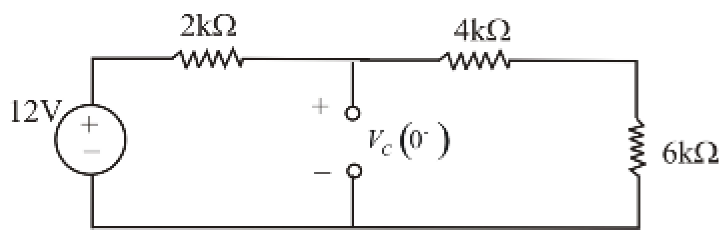
$$\therefore i_0(t) = -6e^{\frac{-t}{\left(\frac{1}{3}\text{m}\right)}}\text{mA}$$

$$\boxed{i_0(t) = -6e^{-3000t}\text{mA}}$$

 Step 1 Add/View Comments

Step1. $i_0(t)$ is of the form $k_1 + k_2 e^{-t/\tau}$

Step2. The initial voltage across the capacitor $V_C(0^-)$ at $t = 0^-$ is calculated from the circuit.



Step 2 Add/View Comments

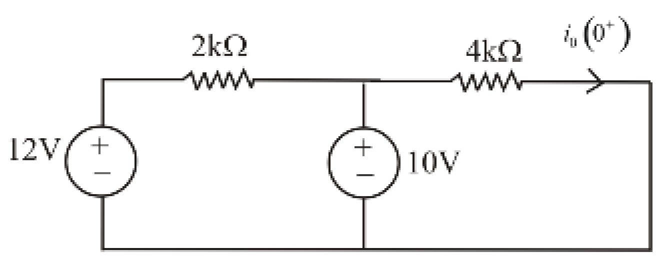
By Voltage division

$$V_C(0^-) = 12 \times \frac{(4k + 6k)}{(2k + 4k + 6k)}$$

$$V_C(0^-) = 10\text{V}$$

 Step 3 Add/View Comments

Step 3. The new circuit for $t = 0^+$ is



 Step 4 Add/View Comments

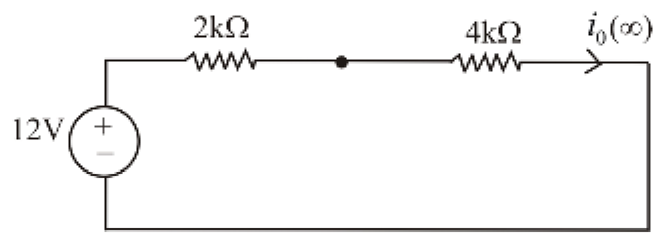
In the second mesh

$$i_0(0^+) = \frac{10}{4k}$$

$$i_0(0^+) = 2.5\text{mA}$$

Add/View Comments

Step 4. The equivalent circuit valid for $t > 5\tau$



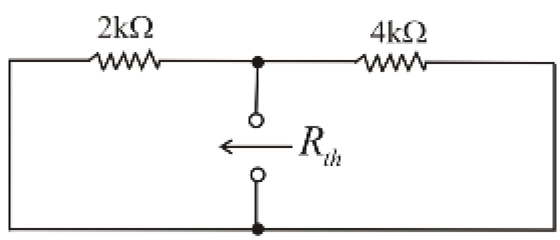
Step 6 Add/View Comments

$$i_0(\infty) = \frac{12}{2k+4k}$$

$$i_0(\infty) = 2mA$$

Add/View Comments

Step 5. The Thevenin equivalent resistance, obtained by looking into the open circuit terminals of the capacitor.



Step 8 Add/View Comments

$$R_{th} = \frac{2k \times 4k}{2k + 4k}$$

$$= \frac{8}{6} k\Omega$$

$$R_{th} = \frac{4}{3} k\Omega$$

Therefore, the circuit time constant is

$$\tau = R_{th} C$$

$$= \left(\frac{4}{3}k\right)\left(200 \times 10^{-6}\right)$$

$$\tau = 0.267 s$$

7.17

Step 9

Step 6. $k_1 = i_0(\infty)$

$= 2\text{mA}$

$k_2 = i_0(0^+) - i_0(\infty)$

$= 2.5 - 2$

$k_2 = 0.5\text{mA}$

Therefore the solution is

$$\boxed{i_0(t) = 2 + 0.5e^{-t/0.27}\ \text{mA}}$$

Step 1

The given circuit is,

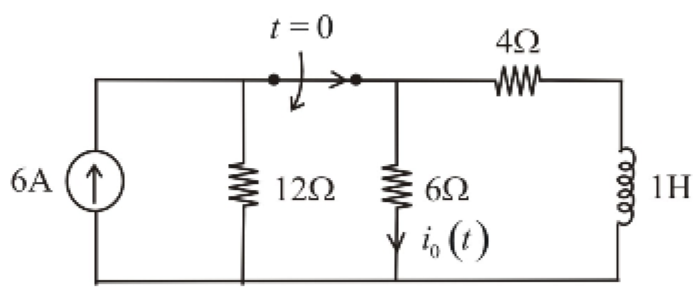


Fig (a)

Step 1: $i_0(t)$ is of the form $K_1 + K_2 e^{\frac{-t}{\tau}}$.

Step 2

Step 2: At $t = 0-$, circuit is as shown is Fig (b), the circuit is in steady state prior to time $t = 0$ therefore the inductor acts as short circuit,

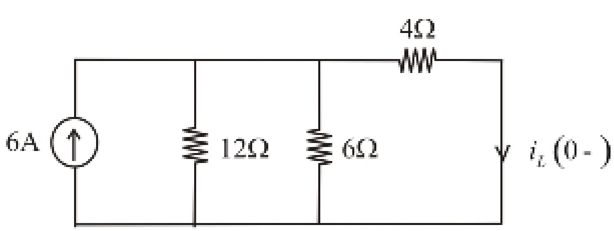


Fig (b)

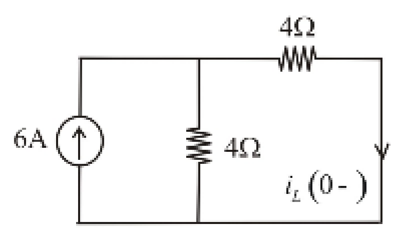


Fig (c)

Step 3 Add/View Comments

12Ω and 6Ω are in parallel, hence replaced as in Fig (c)

$$R_{eq} = \frac{12\times6}{12+6}$$

$$R_{eq} = 4\Omega$$

The initial current through the inductor is calculated from Fig (c),

$$i_L(0-) = 6\times\frac{4}{4+4}$$

$$i_L(0-) = 3\text{ A}$$

Step 4 Add/View Comments

Step 3: Fig (d) is the new circuit valid only at $t = 0+$,

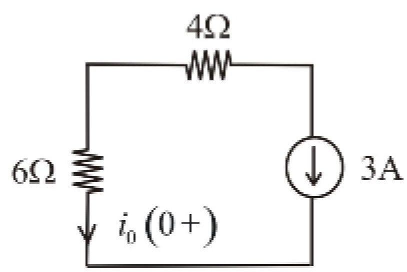


Fig (d)

Step 5 Add/View Comments

The value of the current source that replaces the inductor is,

$i_L(0-) = i_L(0+)$

$i_L(0+) = 3\text{A}$

Hence, $i_0(0+) = -3\text{A}$

Step 6 Add/View Comments

Step 4: The equivalent circuit, valid for $t > 5\tau$, is shown in Fig (e)

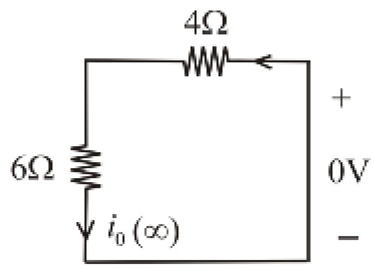


Fig (e)

$\therefore i_0(\infty) = 0\ \text{A}$

 Step 7 Add/View Comments

Step 5: The Thevenin equivalent resistance R_{Th} as seen into the open circuit terminals of the inductor

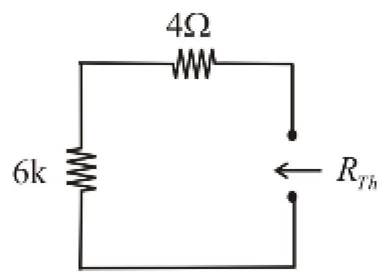


Fig (f)

$R_{\text{Th}} = 6 + 4$
$R_{\text{Th}} = 10\Omega$

Step 8 Add/View Comments

Therefore the time constant is,

$$\tau = \frac{L}{\mathrm{R}_{\text{Th}}}$$
$$\tau = \frac{1}{10}$$
$$\tau = 0.1\text{s}$$

 Step 9 Add/View Comments

Step 6: $K_1 = i_0(\infty)$

$K_1 = 0$

$K_2 = i_0(0+) - i_0(\infty)$

$K_2 = -3\,\text{A}$

$$i_0(t) = -3e^{-\frac{t}{0.1}}\,\text{A}$$

$$\boxed{i_0(t) = -3e^{-10t}\,\text{A}}$$

7.18

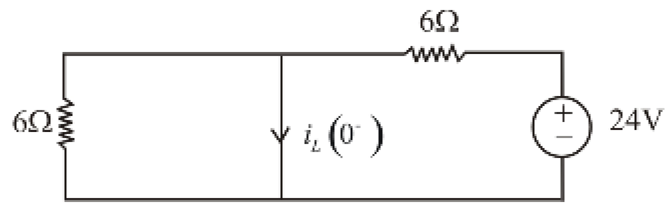
Step 1 Add/View Comments

Step 1: $i_0(t)$ is of the form $k_1 + k_2 e^{-t/\tau}$

Step 2 Add/View Comments

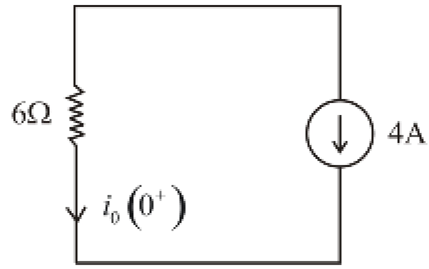
Step 2: The initial current through the inductor is obtained form the circuit at $t = 0^-$

$$i_L(0^-) = \frac{24}{6}$$
$$= 4\text{A}$$



Step 3 Add/View Comments

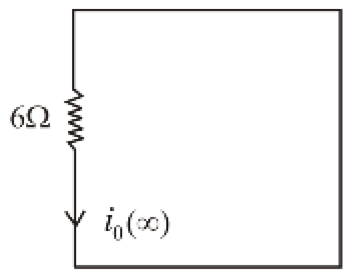
Step 3: The new valid circuit for $t = 0^+$ is



$i_0(0^+) = -4\text{A}$

Step 4 Add/View Comments

Step 4: The equivalent circuit for $t > 5\tau$



$i_0(\infty) = 0\text{A}$

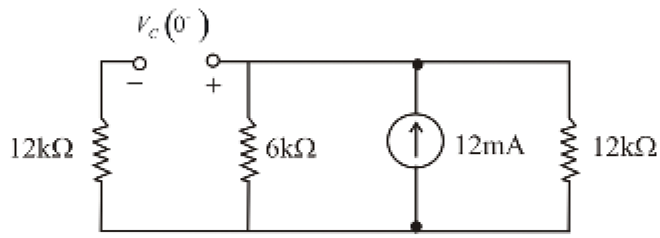
7.19

Add/View Comments

Step1. $i_0(t)$ is of the form $k_1 + k_2 e^{-t/\tau}$

Step 2. The initial voltage across the capacitor is calculated from

$t = 0^-$ The current is



Step 2

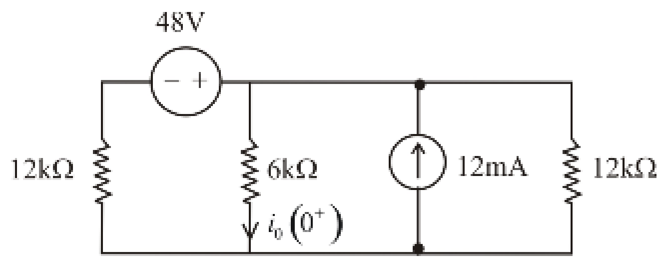
Add/View Comments

Since the capacitor acts as a open circuit, there is no current through $12k\Omega$
Therefore the voltage across capacitor is the voltage across $6k\Omega$

$$i_{6k\Omega} = (12m)\frac{12k}{(12k+6k)}$$
$$= 12 \times \frac{2}{3}$$
$$= 8mA$$
$$V_{6k\Omega} = (6k)(8m)$$
$$= 48V$$

Hence $V_c(0^-) = 48V$

Step3. The new circuit valid for $t = 0^+$ is



Step 4

Therefore

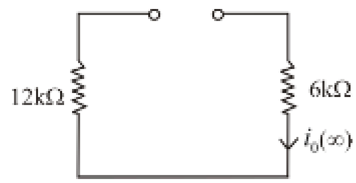
$$i_0(0^+) = \frac{48}{(6k + 12k)}$$

$$= \frac{48}{18k}$$

$$i_0(0^+) = \frac{8}{3} \text{ mA}$$

Step 5 Add/View Comments

Step 4. The equivalent circuit, valid for $t > 5\tau$

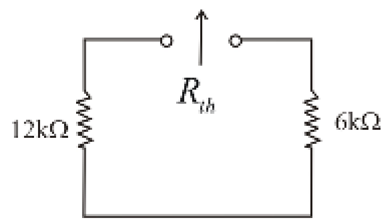


Since there is no source

$i_0(\infty) = 0\,\text{mA}$

Step 6 Add/View Comments

Step 5. The Thevenin equivalent resistance, obtained by looking into the open circuit terminals of the capacitor.



Step 7 Add/View Comments

$$R_{th} = 12\text{k} + 6\text{k}$$
$$R_{th} = 18\text{k}\Omega$$

Therefore, the circuit time constant is

$$\tau = R_{th}C$$
$$= 18\times10^{3}\times200\times10^{-6}$$
$$= 3.6\text{s}$$

Step 8 Add/View Comments

Step 6.

$$k_1 = i_0(\alpha)$$
$$= 0\text{mA}$$
$$k_2 = i_0(0^+) - i_0(\alpha)$$
$$= \frac{8}{3} - 0$$
$$= \frac{8}{3}\text{mA}$$

Therefore the solution is

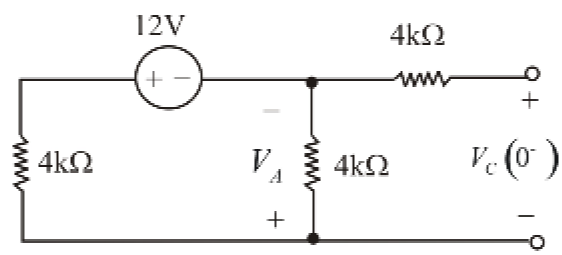
$$\boxed{i_0(t) = \frac{8}{3}e^{-t/3.6}\ \text{mA}}$$

7.21

Add/View Comments

Step1. $i_0(t)$ is of the form of $k_1 + k_2 e^{-t/\tau}$

Step2. The initial voltage across the capacitor $V_C(0^-)$ is calculated from



Step 2 has been challenged - view comments for detail   Add/View Comments (1)

Since there is no current through $4k\Omega$ due to open circuit

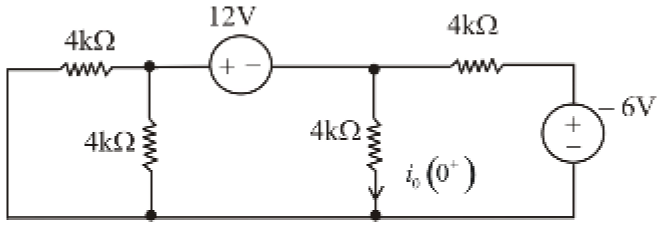
Hence $V_C(0^-) = -V_A$

The voltage across $4k\Omega$ is by voltage division

$$V_A = (12)\left[\frac{4k}{4k+4k}\right]$$
$$= 6V$$

Hence $V_C(0^-) = -6V$

Step 3. The new valid circuit at $t = 0^+$ is

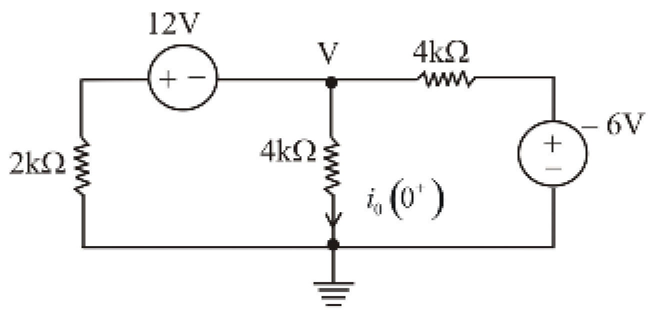


Step 4

Since 4kΩ and 4kΩ are in parallel

$$R_{eq} = \frac{4k \times 4k}{4k + 4k}$$

$$R_{eq} = 2k\Omega$$



Step 5 Add/View Comments

Writing KCL equation at the top node

$$\frac{V-(-12)}{2k}+\frac{V}{4k}+\frac{V-(-6)}{4k}=0$$

$$\frac{V+12}{2k}+\frac{V}{4k}+\frac{V+6}{4k}=0$$

$$2V+24+V+V+6=0$$

$$4V=-30$$

$$V=\frac{-15}{2}\text{ V}$$

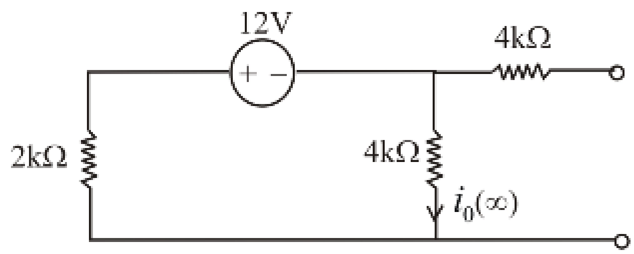
Step 6 Add/View Comments

Hence

$$i_0(0^+)=\frac{V}{4k}=\frac{-15}{2\times 4k}$$

$$i_0(0^+)=\frac{-15}{8}\text{mA}$$

Step 4. The equivalent circuit for $t > 5\tau$

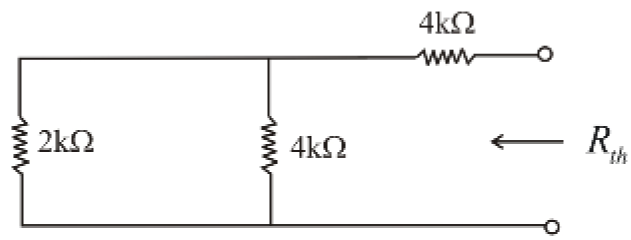


$$i_0(\infty) = \frac{-12}{2k + 6k}$$

$$i_0(\infty) = -2\text{mA}$$

Step 8

Step 5. The Thevenin equivalent circuit is found by



Step 9

$$R_{th} = 4k\Omega + (2k \| 4k)$$
$$= 4k + \frac{4}{3}k$$
$$R_{th} = \frac{16}{3}k\Omega$$

Therefore, the circuit time constant is

$$\tau = R_{th}\,C$$
$$= \frac{16}{3} \times 10^3 \times 200 \times 10^{-6}$$
$$= 1.067\text{s}$$

Step 10

Step 6. $k_1 = i_0(\infty)$

$$= -2\text{mA}$$
$$k_2 = i_0(0^+) - i_0(\infty)$$
$$= \frac{-15}{8} + 2$$
$$= \frac{1}{8}\text{mA}$$

Therefore the solution is

$$\boxed{i_0(t) = -2 + \frac{1}{8}e^{-t/1.067}\ \text{mA}}$$

7.23

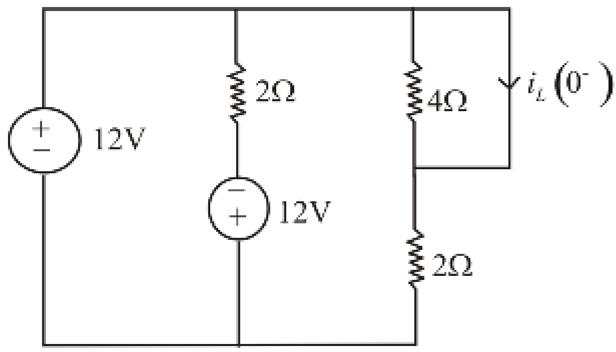
Add/View Comments

Step 1: $V_0(t)$ is of the form $k_1 + k_2 e^{-t/\tau}$

Step 2

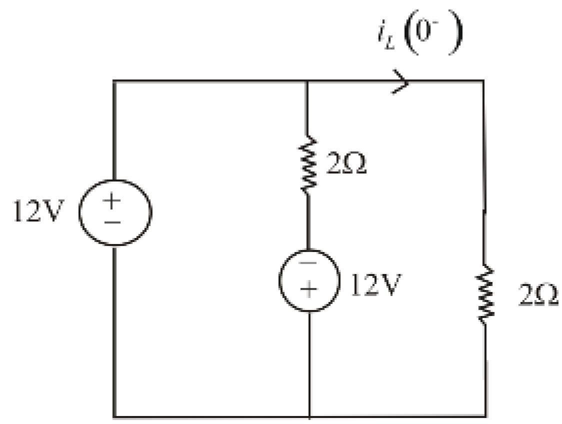
Add/View Comments

Step 2: The initial current through the inductor $i_L(0^-)$ is



 Step 3

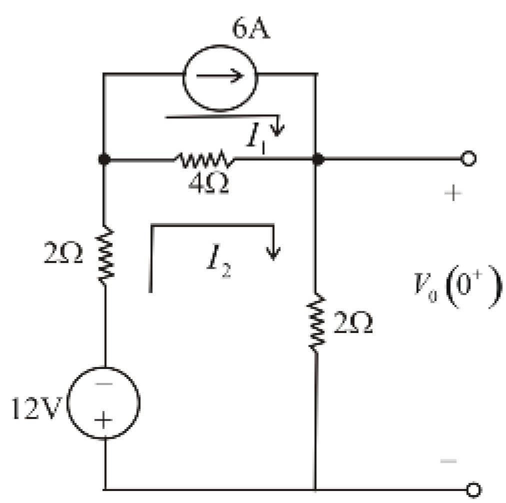
Since 4Ω is in parallel with a short circuit.



$$i_L(0^-) = \frac{12}{2} = 6\text{A}$$

 Step 4

Step 3: The new valid circuit at $t = 0^+$ is



 Step 5 Add/View Comments

Now by mesh analysis

$I_1 = 6\text{A}$

KVL in the second mesh gives

$$12 + 2I_2 + 4(I_2 - I_1) + 2I_2 = 0$$

$$8I_2 - 24 + 12 = 0$$

$$8I_2 = 12$$

$$I_2 = \frac{12}{8}\text{A}$$

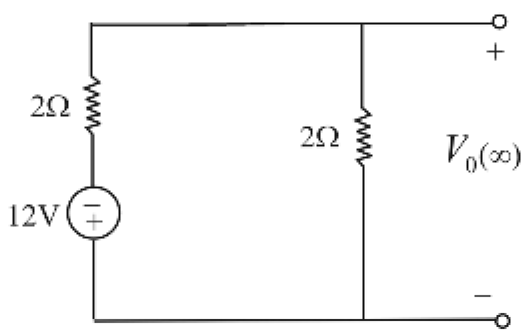
$$I_2 = \frac{3}{2}\text{A}$$

Hence $V_0(0^+) = \frac{3}{2} \times 2$

$$V_0(0^+) = 3\text{V}$$

 Step 6 Add/View Comments

Step 4: The equivalent circuit for $t > 5\tau$



Step 7 Add/View Comments

Now by voltage division

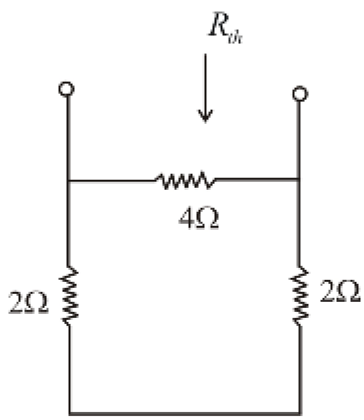
$$V_0(\infty) = -12 \times \frac{2}{2+2}$$

$$= -12 \times \frac{2}{4}$$

$$V_0(\infty) = -6\text{V}$$

 Add/View Comments

Step 5: The Thevenin equivalent resistance is found



Step 9 Add/View Comments

$$R_{th} = 4 \,||\, (2+2)$$
$$= 4 \,||\, 4$$
$$R_{th} = 2\Omega$$

Therefore circuit time constant is,

$$\tau = \frac{L}{R_{th}} = \frac{\left(\frac{1}{3}\right)}{2} = \frac{1}{6}$$

 Add/View Comments

Step 6: $k_1 = V_0(\infty)$
$$= -6\text{V}$$
$$k_2 = V_0(0^+) - V_0(\infty)$$
$$= 3 - (-6)$$
$$= 9\text{V}$$

Therefore the solution is

$$\boxed{V_0(t) = -6 + 9e^{-t/0.167}\ \text{V}}$$

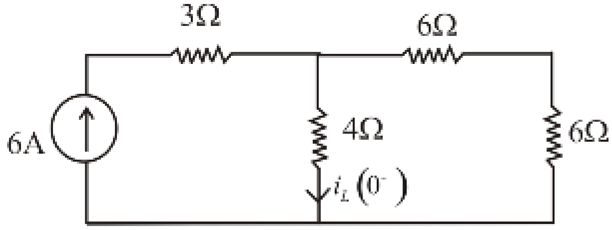
7.25

Add/View Comments

Step 1: $V_0(t)$ is of the form $k_1 + k_2 e^{-t/\tau}$

Step 2 Add/View Comments

Step 2: The initial current through the inductor $i_L(0^-)$ is given by



Step 3 Add/View Comments

By current division

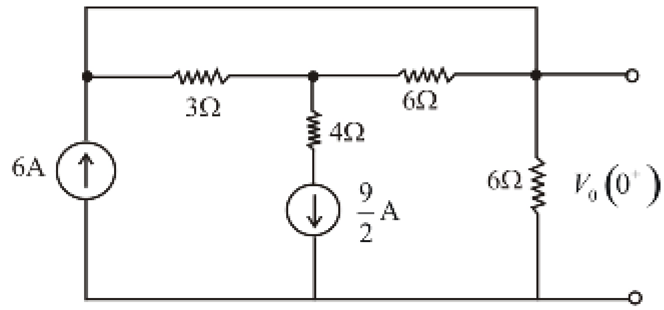
$$i_L(0^-) = 6 \times \left[\frac{6+6}{4+6+6}\right]$$

$$= 6 \times \frac{12}{16}$$

$$i_L(0^-) = \frac{9}{2}\,\text{A}$$

 Add/View Comments

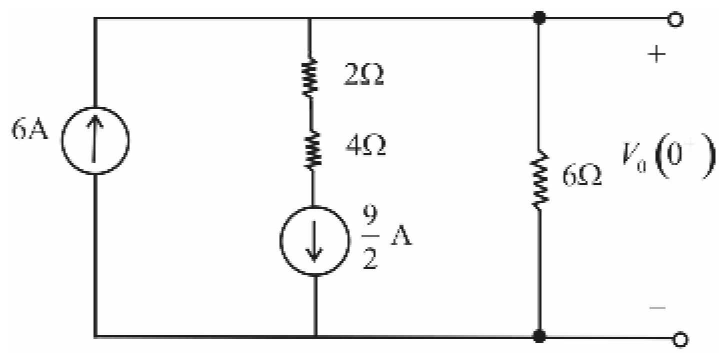
Step 3: The new valid circuit at $t = 0^+$ s



Step 5

Add/View Comments

We see that 3Ω and 6Ω are in parallel. $R_{eq} = 2\Omega$



Step 6 Add/View Comments

Current through 6Ω is, $i_{6\Omega} = 6 - \frac{9}{2}$

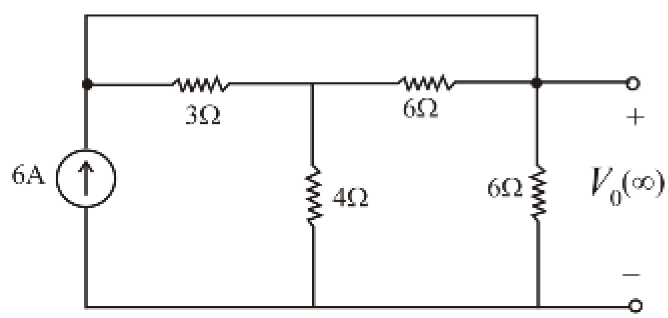
$$= \frac{3}{2}\text{A}$$

Hence $V_0\left(0^+\right) = (6)\left(\frac{3}{2}\right)$

$$V_0\left(0^+\right) = 9\text{V}$$

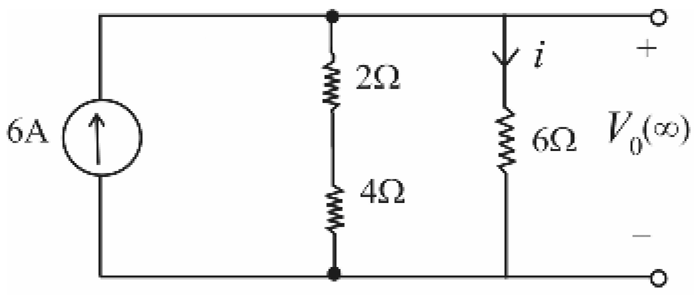
Step 7 Add/View Comments

Step 4: The equivalent circuit for $t > 5\tau$



 Add/View Comments

Since resistors 3Ω and 6Ω are in parallel, $R_{eq} = 2\Omega$



Step 9

Add/View Comments

Current through 6Ω by current division

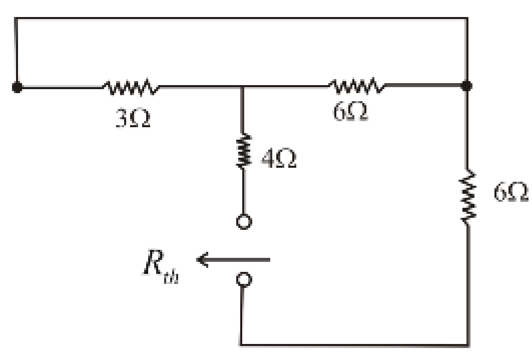
$$i = 6\left[\frac{6}{6+2+4}\right]$$
$$= 3\text{A}$$

Therefore $V_0(\infty) = 6(3)$

$$V_0(\infty) = 18\text{V}$$

 Add/View Comments

Step 5: The thevenin equivalent resistance for the circuit



Step 11

$$R_{th} = 4+6+(3\|6)$$
$$= 4+6+\left(\frac{3\times 6}{3+6}\right)$$
$$R_{th} = 4+6+2$$
$$= 12\Omega$$

Therefore circuit time constant is

$$\tau = \frac{L}{R_{th}}$$
$$= \frac{2}{12}$$
$$= \frac{1}{6}$$
$$\tau = 0.167\,\text{s}$$

Step 12

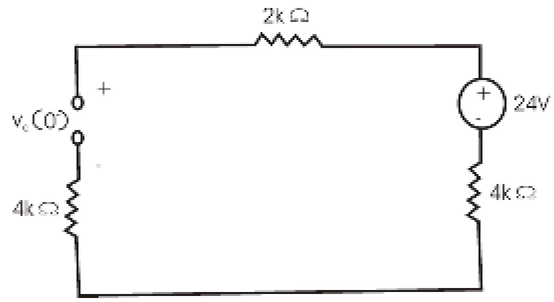
Step 6: $k_1 = V_0(\infty)$
$$= 18\text{V}$$
$$k_2 = V_0(0^+) - V_0(\infty)$$
$$= 9-18$$
$$= -9\text{V}$$

Therefore the solution is

$$V_0(t) = 18 - 9e^{-\frac{t}{0.167}}\ \text{V}$$
$$\boxed{V_0(t) = 18 - 9e^{-6t}\ \text{V}}$$

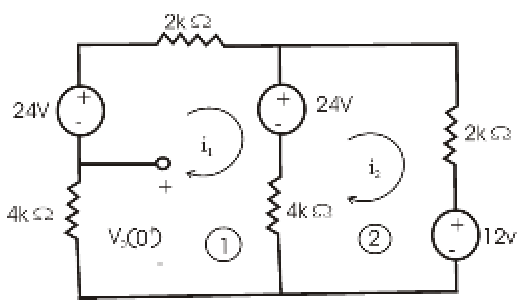
7.26

At $t = 0^-$



$$V_c(0^-) = 24\text{ V}$$
$$V_c(0^+) = 24\text{ V}$$

At $t = 0^+$



Step 2 Add/View Comments

By applying KVL to the loop (1)

$$2Ki_1 + 24 + 4Ki_1 - 4Ki_2 + 4Ki_1 - 24 = 0$$

$$\Rightarrow \quad 10Ki_1 - 4Ki_2 = 0 \qquad \rightarrow (1)$$

By applying KVL to loop (2)

$$2Ki_2 + 12 + 4Ki_2 - 4Ki_2 - 24 = 0$$

$$\Rightarrow \quad 4Ki_1 - 6Ki_2 = 12 \qquad \rightarrow (2)$$

By solving equation (1) & (2) we get

$i_1 = 1.1 \text{ mA},$

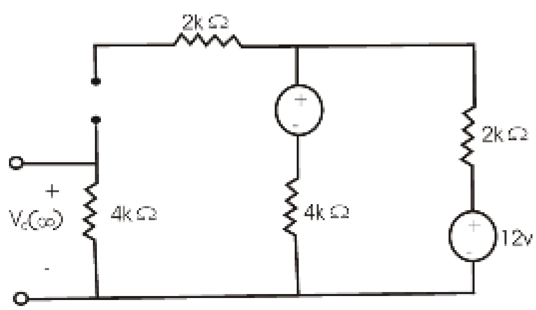
$i_2 = 2.727 \text{ mA},$

$V_0(0^+) = -i_1 \times 4K$

$-1.1m \times 4K$

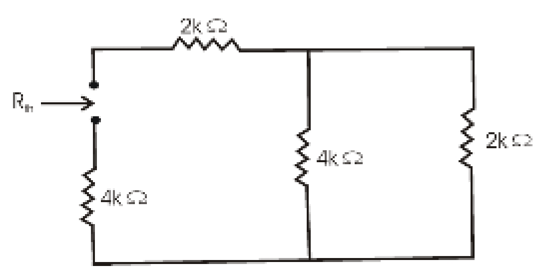
$V_0(0^+) = -4.4V$

At $t = \infty$



$V_0(\infty) = 0$

To find R_{th}



$$4\,\text{K}\Omega \parallel 2\,\text{K}\Omega$$
$$= 1.333\,\text{K}\Omega$$

$2\text{K}\Omega$, $1.333\,\text{K}\Omega$ and $4\text{K}\Omega$ are in series

$$\therefore \quad R_{th} = 7.333\text{K}\Omega$$
$$T = R_{th}C$$
$$= 7.333\,\text{K} \times 50\mu$$
$$\Rightarrow \quad T = 0.3667 \text{ sec}$$
$$\therefore \quad V_c(t) = V_c(\infty) + V_c(0^+) - V_c(\infty)\, e^{\frac{-t}{T}} \text{ V}$$

$$\boxed{V_c(t) = 4.4\, e^{\frac{-t}{0.3667}} \text{ V}} \quad \text{Ans.}$$

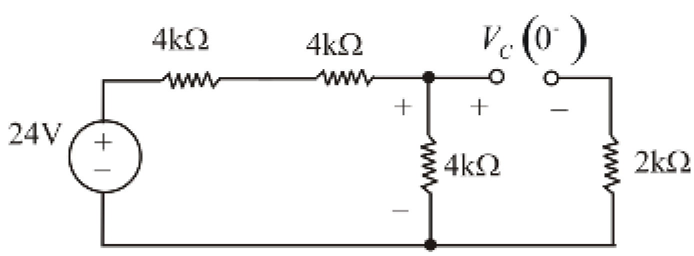
7.27 Add/View Comments

Step 1. $V_0(t)$ is of the form $k_1 + k_2 e^{-t/\tau}$

Step 2

Add/View Comments

Step 2. The initial voltage across the capacitor $V_C(0^-)$ at $t = 0^-$ is calculated from circuit.



Step 3

Add/View Comments

The voltage across $4\text{k}\Omega$ is,

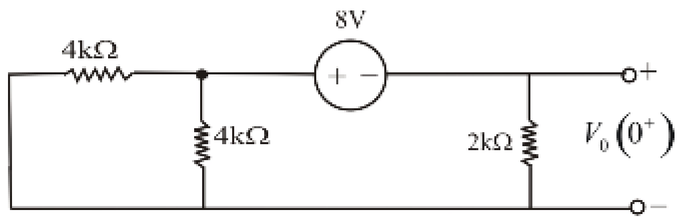
$$V_{4k\Omega} = 24 \times \frac{4\text{k}}{4\text{k}+4\text{k}+4\text{k}}$$
$$= 8\text{V}$$

Hence $V_C(0^-) = V_{4k\Omega}$

$$V_C(0^-) = 8\text{V}$$

Step 4 Add/View Comments

Step 3. The new valid circuit for $t = 0^+$ is



Step 5 Add/View Comments

$V_0(0^+)$ by voltage division

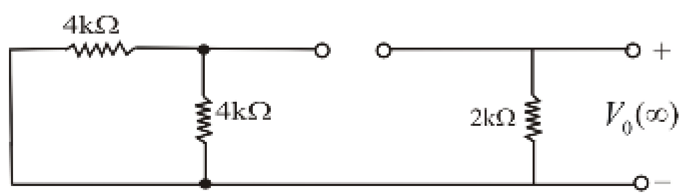
$$V_0(0^+) = (-8)\left(\frac{2\text{k}}{2\text{k} + (4\text{k}\|4\text{k})}\right)$$

$$= (-8)\left(\frac{2\text{k}}{2\text{k} + 2\text{k}}\right)$$

$$V_0(0^+) = -4\text{V}$$

Step 6 Add/View Comments

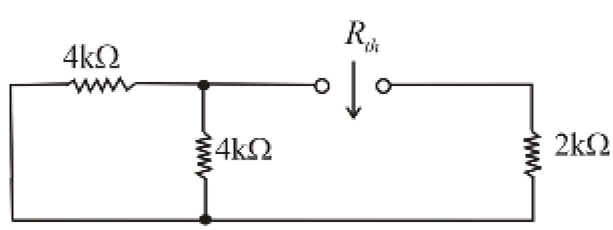
Step 4. The equivalent circuit for $t > 5\tau$



$V_0(\infty) = 0\text{V}$

Step 7 Add/View Comments

Step 5. The thevenin equivalent resistance is calculated from



Step 8 Add/View Comments

$$R_{th} = 2k + (4k \| 4k)$$
$$= 2k + 2k$$
$$R_{th} = 4k\Omega$$

Therefore, the circuit time constant is

$$\tau = R_{th} C$$
$$= (4\times10^3)(200\times10^{-6})$$
$$\tau = 0.8s$$

Step 9 Add/View Comments

Step 6. $k_1 = V_0(\infty)$

$$= 0V$$

$$k_2 = V_0(0^+) - V_0(\infty)$$
$$= -4 - 0$$
$$= -4V$$

Therefore the solution is

$$\boxed{V_0(t) = -4e^{-t/0.8}\ V}$$

7.28

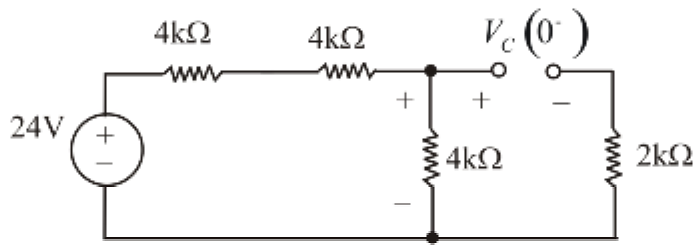
Add/View Comments

Step1. $i_0(t)$ is of the form $k_1 + k_2 e^{-t/\tau}$

Step 2

Add/View Comments

Step2. The initial voltage across the capacitor $V_C(0^-)$ at $t = 0^-$ is calculated from the circuit.



Step 3

Add/View Comments

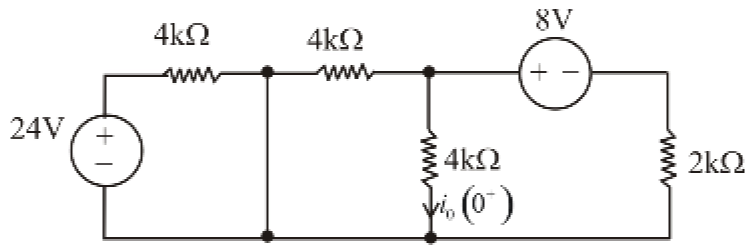
Since there is a open circuit due to capacitor, no current flows through the 2kΩ and hence the voltage across the capacitors is same as the voltage across $4k\Omega$
By voltage division,

$$V_C(0^-) = 24 \times \frac{4k}{(4k + 4k + 4k)}$$

$$V_C(0^-) = 8V$$

Add/View Comments

Step3. The new circuit valid from $t = 0^{+}$ is



Step 5

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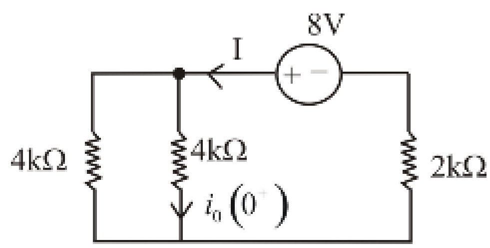
Modified as,



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The total current I is given by

$$I = \frac{8}{2k+(4||4)k}$$
$$= \frac{8}{(2+2k)}$$
$$= 2mA$$

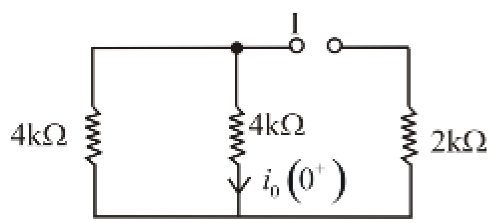
By current division

$$i_0(0^+) = 2m \times \frac{4k}{4k+4k}$$
$$i_0(0^+) = 1mA$$

Step 7

Add/View Comments

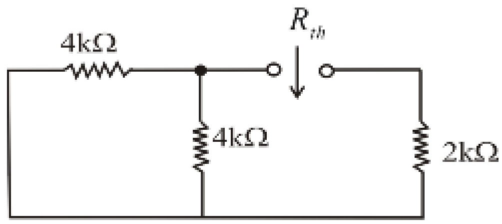
Step 4. The equivalent circuit for $t > 5\tau$



$$i_0(\infty) = 0mA$$

 Add/View Comments

Step 5. The Thevenin equivalent resistance is obtained from



Step 9

Add/View Comments

$$R_{th} = 2\text{k} + 4\text{k}||4\text{k}$$
$$= 2\text{k} + 2\text{k}$$
$$R_{th} = 4\text{k}\Omega$$

Therefore the circuit time constant is,

$$\tau = R_{th}C$$
$$= \left(4\times10^{3}\right)\left(200\times10^{-6}\right)$$
$$\tau = 0.8\text{s}$$

 Add/View Comments

Step 6. $k_1 = i_0(\infty)$

$$= 0\text{mA}$$
$$k_2 = i_0\left(0^+\right) - i_0(\infty)$$
$$= 1 - 0$$
$$= 1\text{mA}$$

Therefore the solution is,

$$\boxed{i_0(t) = 1e^{-t/0.8}\ \text{mA}}$$

7.29

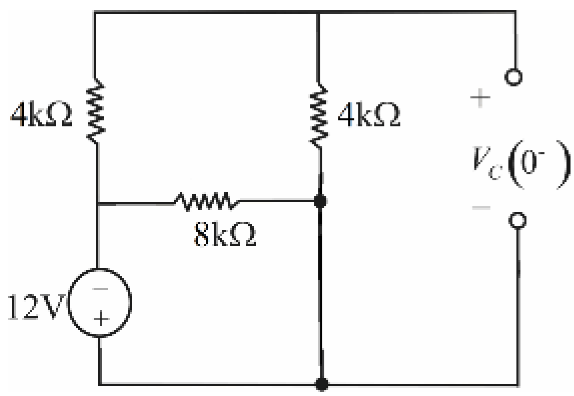
Add/View Comments

Step 1: $V_0(t)$ is of the form $k_1 + k_2 e^{-\frac{t}{\tau}}$

Step 2

Add/View Comments

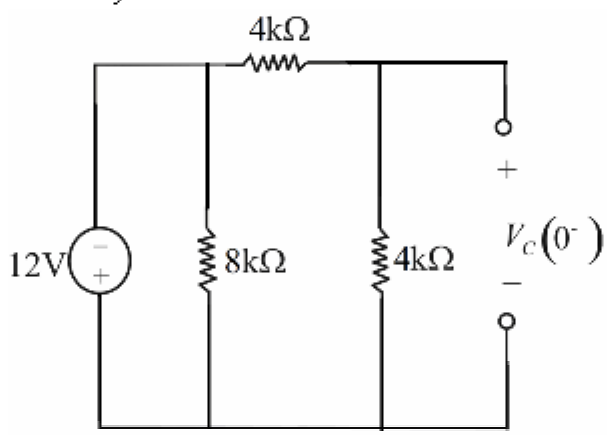
Step 2: The initial voltage across the capacitor is obtained from the circuit.



Step 3

Add/View Comments

Redrawing the circuit carefully



Step 4

Add/View Comments

Therefore by voltage division

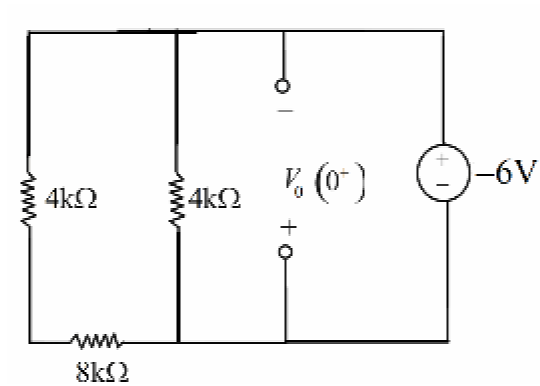
$$V_C(0^-) = -12 \times \frac{4\text{k}}{4\text{k}+4\text{k}}$$

$$= -12 \times \frac{4}{8}$$

$$V_C(0^-) = -6\text{V}$$

Step 5 Add/View Comments

Step 3: the new valid circuit at $t = 0^+$ is

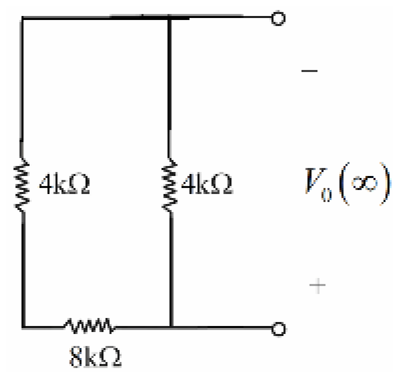


Therefore $V_0(0^+) = 6\text{V}$

Step 6

Add/View Comments

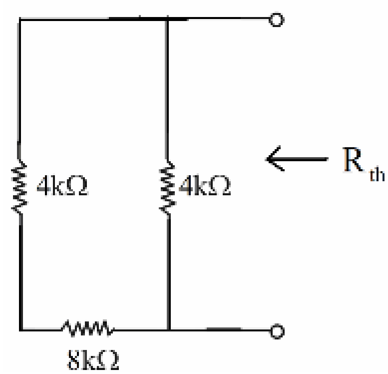
Step 4: The equivalent circuit for $t > 5\tau$



Therefore $V_0(\infty) = 0\text{V}$

Step 7 Add/View Comments

Step 5: The Thevenin equivalent resistance is obtained by



Step 8 Add/View Comments

$$R_{th} = 4k \| (4k + 8k)$$
$$= 4k \| (12k)$$
$$= \frac{4k \times 12k}{4k + 12k}$$
$$= \frac{48k}{16}$$
$$R_{th} = 3\ \text{k}\Omega$$

Step 9 Add/View Comments

Therefore circuit time constant is

$$\tau = R_{th} C$$
$$= (3\times10^{3})(50\times10^{-6})$$
$$= 0.15\,\text{s}$$

Step 10 Add/View Comments

Step 6: $k_1 = V_0(\infty)$
$$= 0\text{V}$$
$$k_2 = V_0(0^+) - V_0(\infty)$$
$$= 6 - 0$$
$$= 6\text{V}$$

Therefore the solution is

$$V_0(t) = 6e^{-\frac{t}{0.15}}\ \text{V}$$

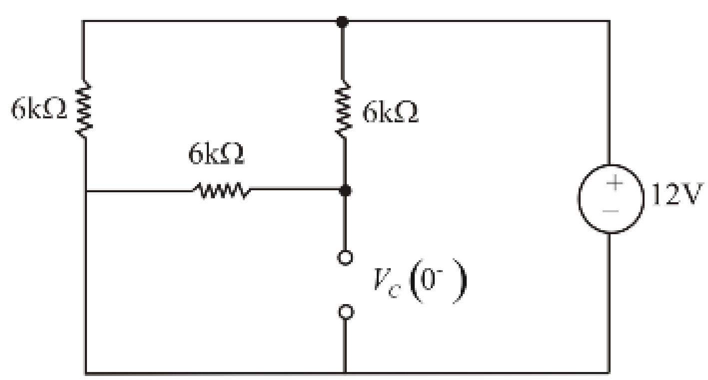
$$\boxed{V_0(t) = 6e^{-6.67t}\ \text{V}}$$

31

7.31 Add/View Comments

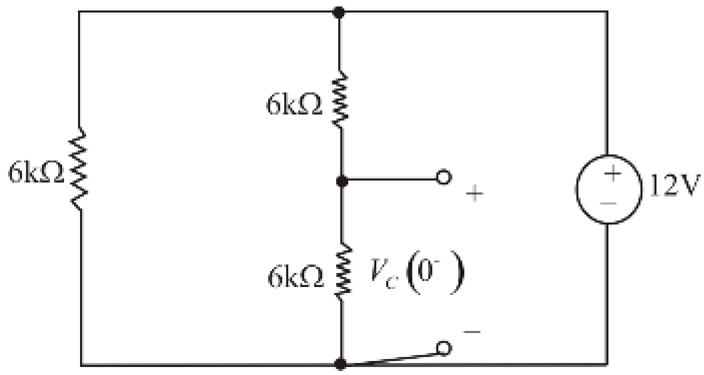
Step 1. $i_0(t)$ is of the form $k_1 + k_2 e^{-t/\tau}$

Step 2. The initial voltage across the capacitor $V_C(0^-)$ is obtained from the circuit.



Step 2 Add/View Comments

The Circuit can be drawn as



Step 3

Add/View Comments

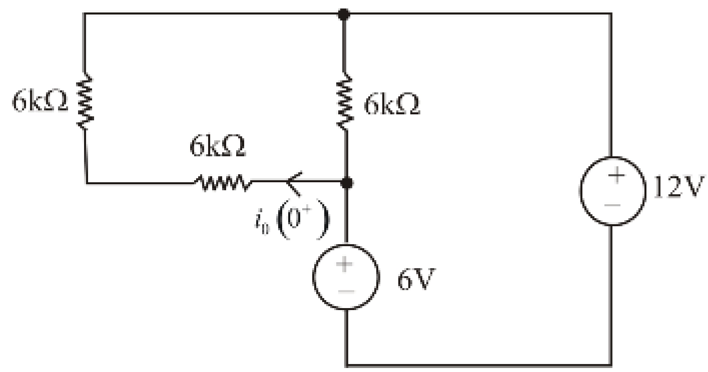
By voltage division

$$V_C(0^-) = \frac{6k}{(6k+6k)}$$

$$V_C(0^-) = 6V$$

Step 4 Add/View Comments

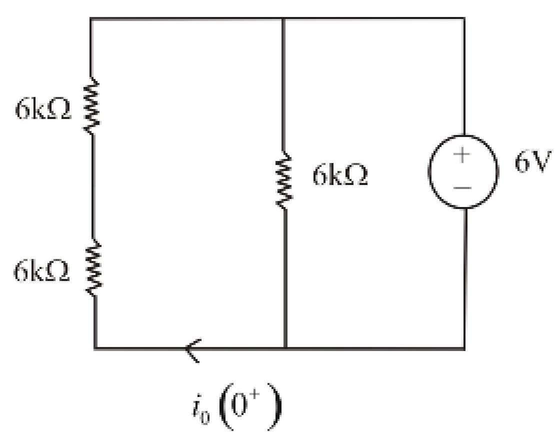
Step 3. The new valid circuit for $t = 0^+$ is



Step 5

Add/View Comments

The circuit can be drawn as



 Step 6 Add/View Comments

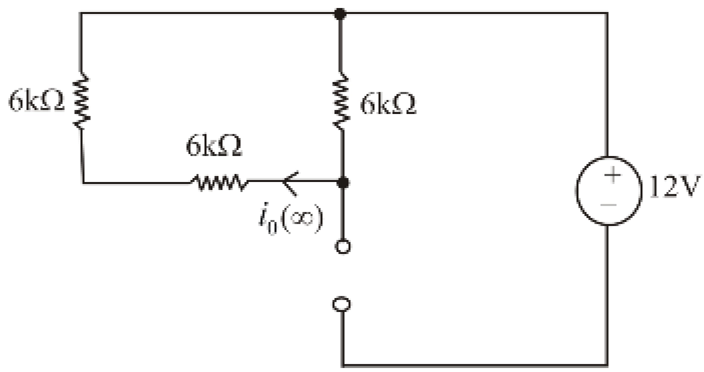
By $i_0\left(0^+\right)=\dfrac{-6}{6k+6k}$

$$=\frac{-6}{12k}$$

$$i_0\left(0^+\right)=-\frac{1}{2}\text{mA}$$

Step 7 Add/View Comments

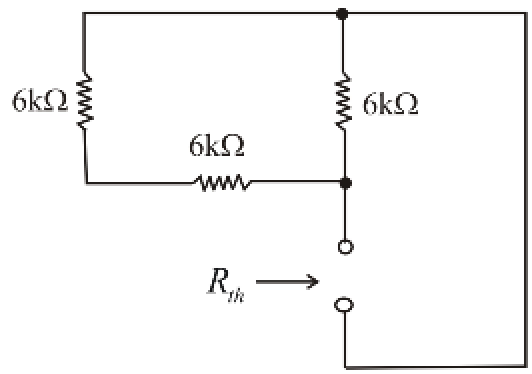
Step 4. The equivalent circuit for $t>5\tau$



$$i_0\left(\infty\right)=0\text{mA}$$

Add/View Comments

Step 5. The Thevenin equivalent can be found by



Step 9

Add/View Comments

$$R_{th} = \left(6\text{k}\|\left(6\text{k}+6\right)\right)$$
$$= \left(6\text{k}\|12\text{k}\right)$$
$$R_{th} = \frac{6\times 12}{6+12}$$
$$R_{th} = 4\text{k}\Omega$$

Therefore, the circuit time constant is

$$\tau = R_{th}\,C$$
$$= 4\times 10^{3}\times 50\times 10^{-6}$$
$$= 0.2s$$

Add/View Comments

Step 6. $k_1 = i_0\left(\infty\right)$

$$= 0\,\text{mA}$$
$$k_2 = i_0\left(0^{+}\right) - i\left(\infty\right)$$
$$= -\frac{1}{2} - 0$$
$$= -\frac{1}{2}\text{ mA}$$

Hence the solution is

$$\boxed{i_0\left(t\right) = -\frac{1}{2}e^{-t/0.2}\text{ mA}}$$

7.32

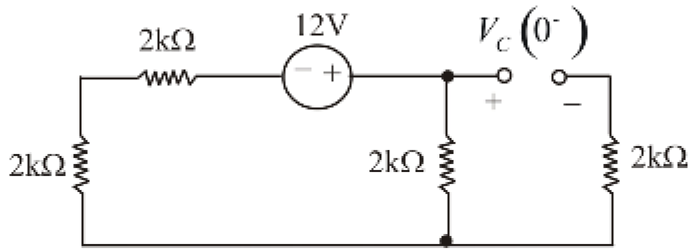
Add/View Comments

Step 1: $i_0(t)$ is of the form $k_1 + k_2 e^{-t/\tau}$

Step 2

Add/View Comments

Step 2: the initial voltage across the capacitor is found by



Step 3

Add/View Comments

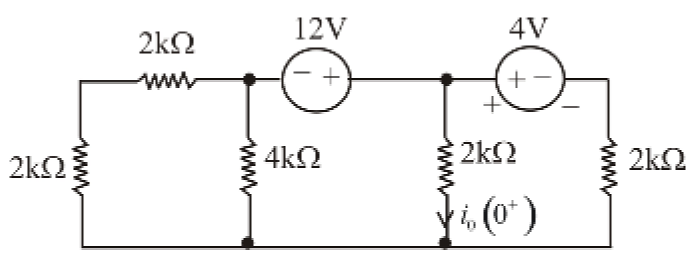
By voltage division

$$V_C(0^-) = 12 \times \frac{2k}{2k + 2k + 2k}$$

$$V_C(0^-) = 4\text{V}$$

Add/View Comments

Step 3: The new valid circuit at $t = 0^+$ is

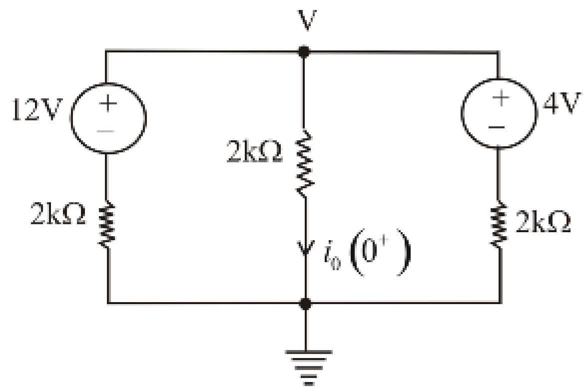


Step 5 Add/View Comments

Since the resistor $2k\Omega$ and $2k\Omega$ are in series and this combination in parallel with $4k\Omega$

$$R_{eq} = (2k + 2k) \| 4k$$
$$= 4k \| 4k$$
$$= 2k\Omega$$

Step 6 Add/View Comments



Add/View Comments

Writing KCL equation at the top node,

$$\frac{V-12}{2k}+\frac{V}{2k}+\frac{V-4}{2k}=0$$

$$3V-16=0$$

$$V=\frac{16}{3}\text{V}$$

$$i_0\left(0^+\right)=\frac{V}{2k}$$

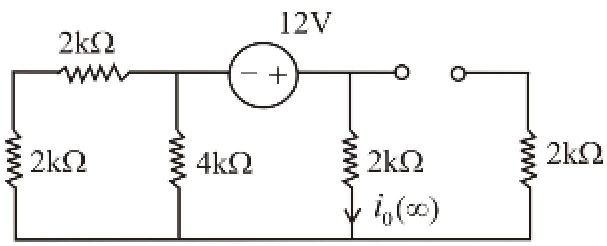
$$=\frac{\left(\frac{16}{3}\right)}{2k}$$

$$i_0\left(0^+\right)=\frac{8}{3}\text{mA}$$

Step 8

Add/View Comments

Step 4: The equivalent circuit for $t>5\tau$



Add/View Comments

$$i_0\left(\infty\right)=\frac{12}{2k+\left(4k\|\left(2k+2k\right)\right)}$$

$$=\frac{12}{2k\left(4k\,\|\,4k\right)}$$

$$=\frac{12}{2k+2k}$$

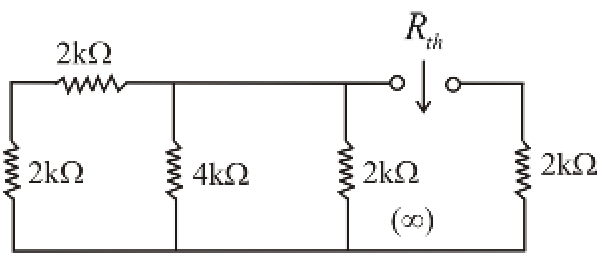
$$i_0\left(\infty\right)=3\text{mA}$$

Step 10

Add/View Comments

Step 5: The Thevenin equivalent resistance can be found by looking into the open circulated terminals of the capacitor

Step 11



Step 12

$$R_{th} = 2k + \{2k \| [4k \| (2k+2k)]\}$$
$$= 2k + \{2k \| [4k \| 4k]\}$$
$$= 2k + \{2k \| 2k\}$$
$$= 2k + 1k$$
$$R_{th} = 3k\Omega$$

Therefore, the circuit time constant is

$$\tau = R_{th}\, C$$
$$= (3 \times 10^3)(200 \times 10^{-6})$$
$$\tau = 0.6\text{s}$$

Step 13

Step 6: $k_1 = i_0(\infty)$
$$= 3\text{mA}$$
$$k_2 = i_0(0^+) - i_0(\infty)$$
$$= \frac{8}{3} - 3$$
$$= -\frac{1}{3}\ \text{mA}$$

Therefore the solution is

$$\boxed{i_0(t) = 3 - \frac{1}{3} e^{-t/0.6}\ \text{mA}}$$

7.33

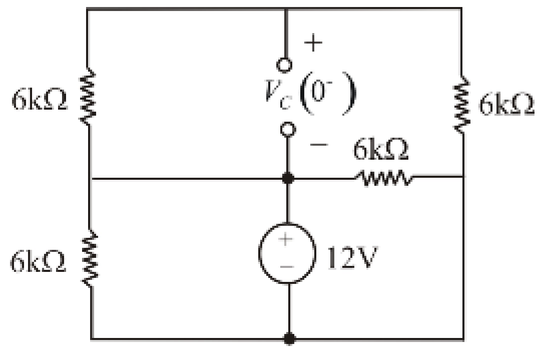
Add/View Comments

Step 1: $V_0(t)$ is of the form $k_1 + k_2 e^{-t/\tau}$

Step 2

Add/View Comments

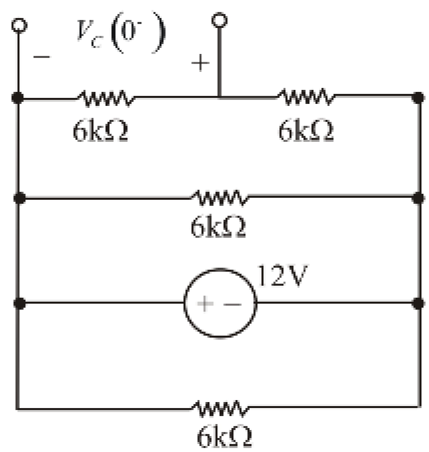
Step 2: The initial voltage across the capacitor is obtained from the circuit.



Step 3

Add/View Comments

Redrawing the circuit carefully



Step 4

Add/View Comments

Therefore by voltage division

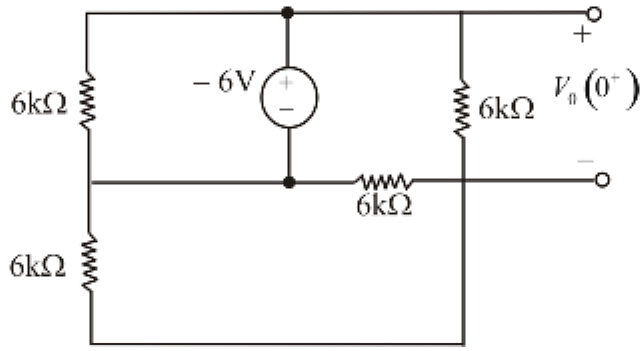
$$V_C(0^-) = -12 \times \frac{6\text{k}}{6\text{k}+6\text{k}}$$

$$= -12 \times \frac{6}{12}$$

$$V_C(0^-) = -6\text{V}$$

 Add/View Comments

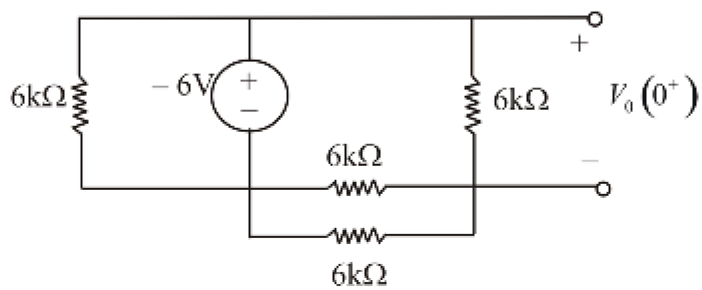
Step 3: the new valid circuit at $t = 0^+$ is



Step 6

Add/View Comments

The circuit can be redrawn as



Step 7 Add/View Comments

By voltage division

$$V_0\left(0^+\right) = -6\left[\frac{6k}{6k + (6k \| 6k)}\right]$$

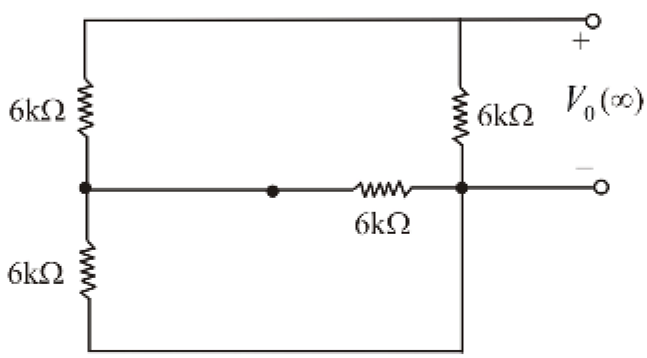
$$= -6\left[\frac{6k}{6k+3k}\right]$$

$$= -6\left[\frac{6}{9}\right]$$

$$V_0\left(0^+\right) = -4\text{V}$$

Step 8 Add/View Comments

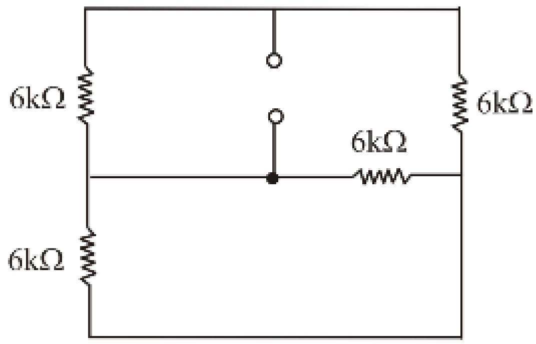
Step 4: The equivalent circuit for $t > 5\tau$



$$V_0(\infty) = 0\text{V}$$

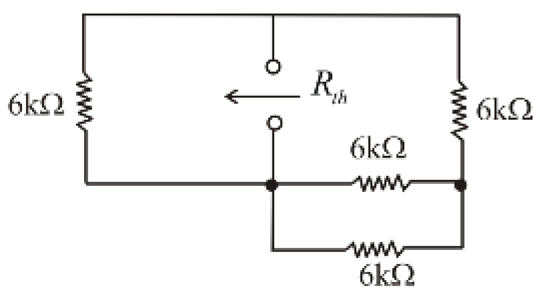
Step 9 Add/View Comments

Step 5: The Thevenin equivalent resistance is obtained by



Step 10 Add/View Comments

The circuit can be redrawn as.



Step 11 Add/View Comments

$$
\begin{aligned}
R_{th} &= 6\|\left(6+\left(6\|6\right)\right) \\
&= 6\|\left(6+3\right) \\
&= 6\|9 \\
&= \frac{6\times 9}{6+9} \\
&= \frac{6\times 9}{15} \\
R_{th} &= \frac{18}{5}\ \text{k}\Omega
\end{aligned}
$$

Step 12 Add/View Comments

Therefore circuit time constant is

$$
\begin{aligned}
\tau &= R_{th}\ C \\
&= \left(\frac{18}{5}\times 10^{3}\right)\left(50\times 10^{-6}\right) \\
&= 0.180\,\text{s}
\end{aligned}
$$

Step 13 Add/View Comments

$$
\begin{aligned}
\text{Step 6: } k_1 &= V_0(\infty) \\
&= 0\text{V} \\
k_2 &= V_0\left(0^{+}\right) - V_0(\infty) \\
&= -4-0 \\
&= -4\text{V}
\end{aligned}
$$

Therefore the solution is

$$\boxed{V_0(t) = -4e^{-t/0.18}\ \text{V}}$$

7.34

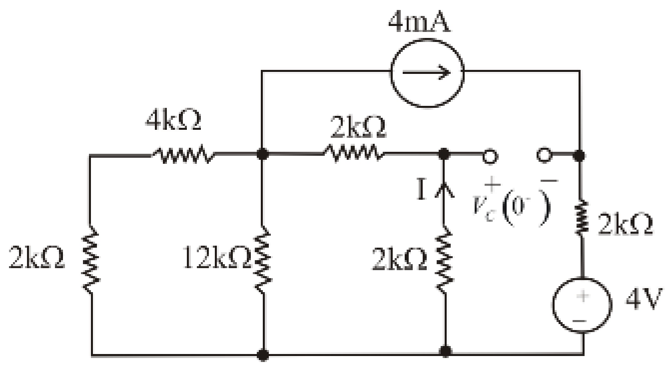
Add/View Comments

Step 1: $i_0(t)$ is in the form $k_1 + k_2 e^{-t/\tau}$

Step 2

Add/View Comments

Step 2: The initial voltage across the capacitor can be found by



Step 3

Add/View Comments

Resistor $4\text{k}\Omega$, $2\text{k}\Omega$ are in series and this in parallel with $12\text{k}\Omega$

$$R_{eq} = 12\text{k}||(4\text{k}+2\text{k})$$
$$= 12\text{k}||6\text{k}$$
$$= \frac{12\times6}{12+6}$$
$$R_{eq} = 4\text{k}\Omega$$

By current division,

$$I = (4\text{m})\left[\frac{4\text{k}}{4\text{k}+2\text{k}+2\text{k}}\right]$$
$$I = 2\text{mA}$$

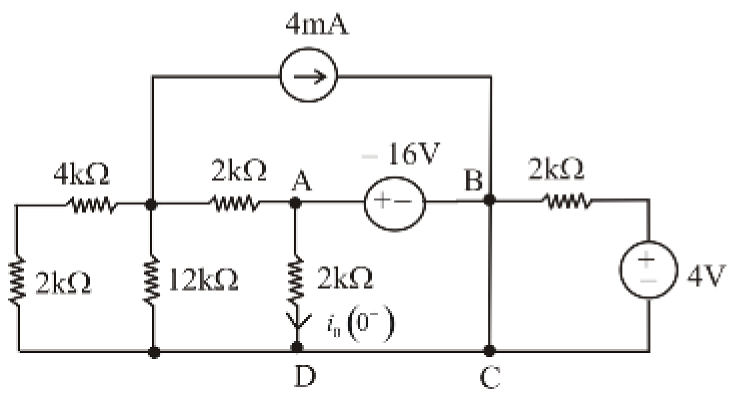
And hence KVL across the loop

$$(2\text{m})(2\text{k}) + V_C(0^-) + (2\text{k})(4\text{m}) + 4 = 0$$
$$4 + V_C(0^-) + 8 + 4 = 0$$
$$V_C(0^-) = -16\text{V}$$

Step 4

Add/View Comments

Step 3: The new valid circuit for $t = 0^+$ is



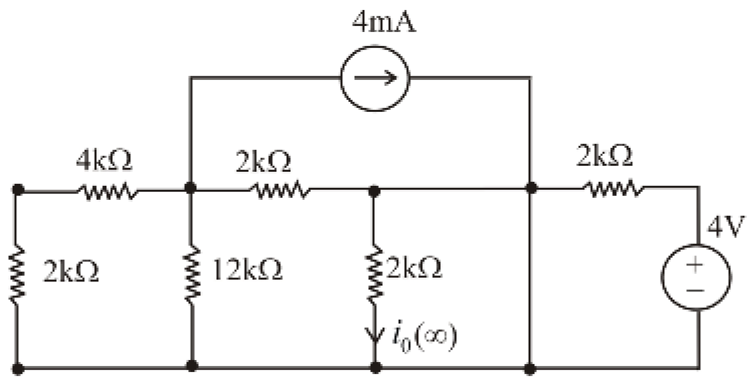
Step 5

Add/View Comments

In the closed loop BADC applying KVL

$$-(-16) + 2k\, i_0(0^+) = 0$$
$$i_0(0^+) = \frac{-16}{2\text{k}}$$
$$i_0(0^+) = -8\text{mA}$$

Step 4: The equivalent circuit for $t > 5\tau$



Step 7

$$i_0(\infty) = (-4\text{m})\left[\frac{4\text{k}}{4\text{k}+4\text{k}}\right]$$

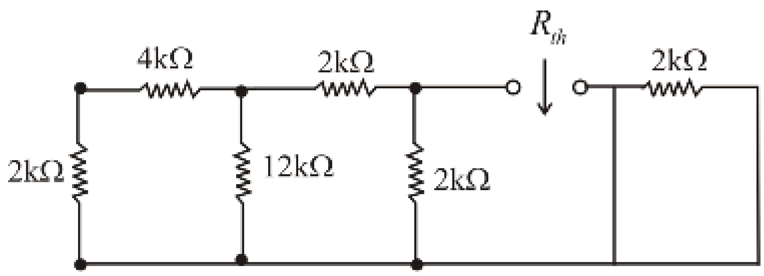
$$i_0(\infty) = -2\text{mA}$$

Since the resistors 4k, 2k are in series and this in parallel with 12kΩ.

$$R_{eq} = 12\text{k}||(4\text{k}+2\text{k})$$
$$= 12\text{k}||6\text{k}$$
$$R_{eq} = 4\text{k}\Omega$$

 Add/View Comments

Step 5: The Thevenin resistance can be found by



Step 9

Add/View Comments

$$
\begin{aligned}
R_{th} &= \{[(4k+2k) \parallel 12k] + 2k\} \parallel 2k \\
&= \{[6k \parallel 12k] + 2k\} \parallel 2k \\
&= \{4k \parallel 2k\} \parallel 2k \\
&= 6k \parallel 2k \\
&= \frac{6 \times 2}{6+2} k \\
&= \frac{12}{8} k \\
R_{th} &= \frac{3}{2} k\Omega
\end{aligned}
$$

Step 10 Add/View Comments

Therefore, the circuit time constant is

$$\tau = R_{th}\ C$$

$$= \frac{3}{2}\times 10^{3}\times 100\times 10^{-6}$$

$$\tau = 0.15\,\text{s}$$

Step 11

Add/View Comments

$$\text{Step 6: } k_1 = i_0(\infty)$$

$$= -2\,\text{mA}$$

$$k_2 = i_0(0^+) - i_0(\infty)$$

$$= -8+2$$

$$= -6\,\text{mA}$$

Therefore the solution is

$$\boxed{i_0(t) = -2-6e^{-t/0.15}\ \text{mA}}$$

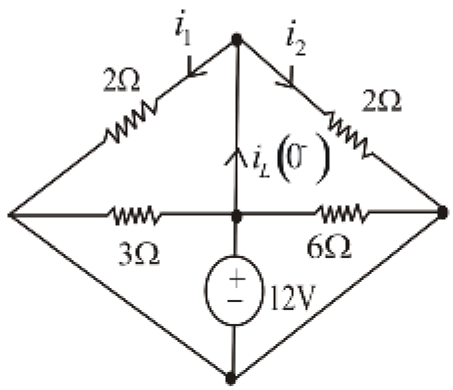
7.35 Add/View Comments

Step 1: $V_0(t)$ is of the form $k_1 + k_2 e^{-t/\tau}$

Step 2

Add/View Comments

Step 2: The initial current through the inductor $i_L(0^-)$ is found by



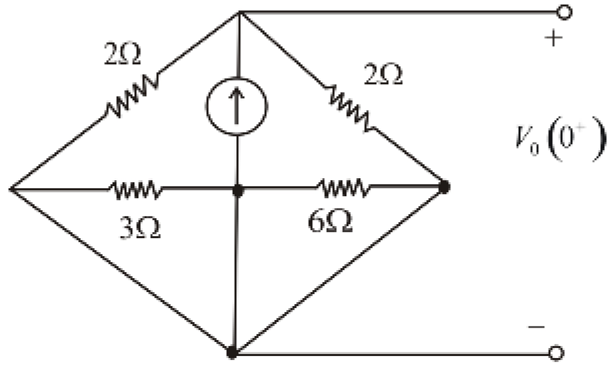
Step 3

Add/View Comments

Observe carefully, we see that the voltage across each element is the same i.e. 12V, due to the short circulated inductor KCL at the top node gives.

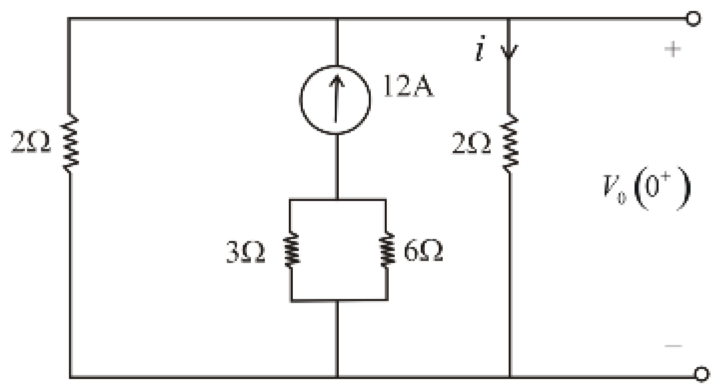
$$i_L(0^-) = i_1 + i_2$$
$$= \frac{12}{2} + \frac{12}{2}$$
$$= 6 + 6$$
$$i_L(0^-) = 12\text{A}$$

Step 3: The new valid circuit at $t = 0^+$



Step 5

This circuit can be redrawn as



By current division, current through 2Ω is

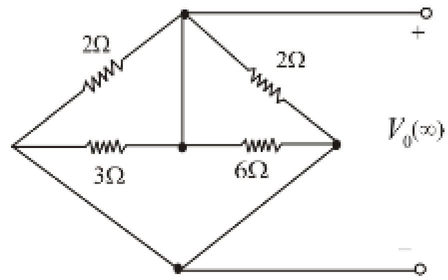
$$i = 12 \times \frac{2}{2+2}$$
$$= 6\text{A}$$

Therefore $V_0(0^+) = (6)(2)$

$$V_0(0^+) = 12\text{V}$$

Step 7 Add/View Comments

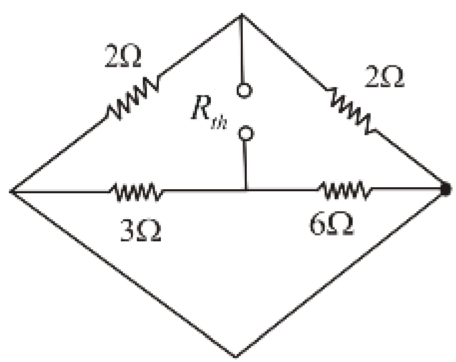
Step 4: The equivalent circuit at $t = 5\tau$



$V_0(\infty) = 0\text{V}$

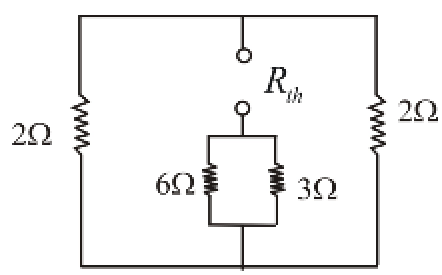
Step 8 Add/View Comments

Step 5: The thevenin equivalent resistance is found by



Step 9 Add/View Comments

This circuit is redrawn as



Step 10 Add/View Comments

$$R_{th} = (6 \| 3) + (2 \| 2)$$
$$= 2 + 1$$
$$R_{th} = 3\Omega$$

Therefore circuit time constant is

$$\tau = \frac{L}{R_{th}}$$
$$= \frac{2}{3}$$
$$\tau = 0.67\,\text{s}$$

Step 11 Add/View Comments

Step 6: $k_1 = V_0(\infty)$

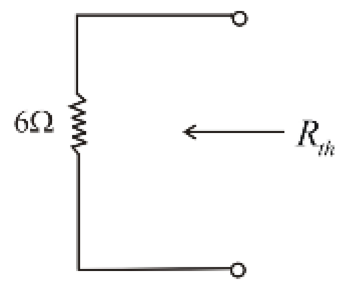
$$= 0$$
$$k_2 = V_0(0^+) - V_0(\infty)$$
$$= 12 - 0$$
$$= 12$$

Therefore the solution is

$$\boxed{V_0(t) = 12e^{-t/0.67}\ \text{V}}$$

Step 5 Add/View Comments

Step 5: The Thevenin equivalent resistance is obtained from



$R_{th} = 6\Omega$

Step 6 Add/View Comments

Therefore the circuit time constant is,

$$\tau = \frac{L}{R_{th}} = \frac{2}{6} = \frac{1}{3}s = 0.33s$$

8.6 Calculate the current in the resistor in Fig. P8.6 if the voltage input is

(a) $v_1(t) = 10\cos(377t + 180°)$ V.

(b) $v_2(t) = 12\sin(377t + 45°)$ V.

Give the answers in both the time and frequency domains.

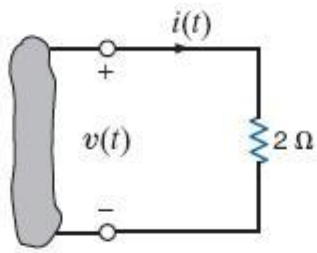
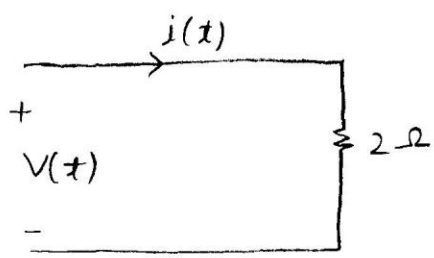


Figure P8.6

SOLUTION:



(a) $V_1(t) = 10\cos(377t + 180°)$ V

$i(t) = \frac{10}{2}\cos(377t + 180°$

$i(t) = 5\cos(377t + 180°)$ A) A

$\bar{I} = 5 \angle 180°$ A

(b) $V_2(t) = 12\sin(377t + 45°)$ V

$V_2(t) = 12\cos(377t - 45°)$ V

$i(t) = 6\cos(377t - 45°)$ A

$\bar{I} = 6 \angle -45°$ A

8.7 Calculate the current in the capacitor shown in Fig. P8.7 if the voltage input is

(a) $v_1(t) = 10\cos(377t - 30°)$ V

(b) $v_2(t) = 5\sin(377t + 60°)$ V

Give the answers in both the time and frequency domains.

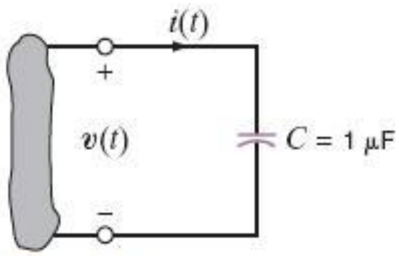
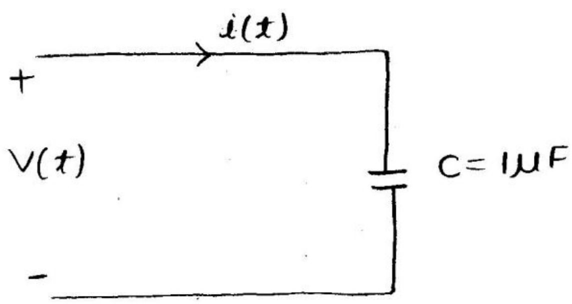


Figure P8.7

SOLUTION:



(a) $V_1(t) = 10\cos(377t - 30°)$ V

$$i(t) = C\frac{dV_1(t)}{dt}$$

$$\frac{dV_1(t)}{dt} = -3770\sin(377t - 30°)$$

$$i(t) = (1\times10^{-6})(-3770\sin(377t - 30°))$$

$$i(t) = -3.77\sin(377t - 30°)\text{ mA}$$

$$i(t) = 3.77\sin(377t + 150°)\text{ mA}$$

$$i(t) = 3.77 \cos(377t + 60^\circ) \text{ mA}$$

$$\bar{I} = 3.77\angle 60^\circ \text{ mA}$$

(b) $$v_2(t) = 5\sin(377t + 60^\circ) \text{ V}$$

$$v_2(t) = 5\cos(377t - 30^\circ) \text{ V}$$

$$i(t) = C\frac{dv_2(t)}{dt}$$

$$\frac{dv_2(t)}{dt} = -1885 \sin(377t - 30^\circ)$$

$$i(t) = (1 \times 10^{-6})(-1885 \sin(377t - 30^\circ))$$

$$i(t) = -1.89 \sin(377t - 30^\circ) \text{ mA}$$

$$i(t) = 1.89 \sin(377t + 150^\circ) \text{ mA}$$

$$i(t) = 1.89 \cos(377t + 60^\circ) \text{ mA}$$

$$\bar{I} = 1.89\angle 60^\circ \text{ mA}$$

8.11 Find the frequency-domain impedance, **Z**, as shown in Fig. P8.11.

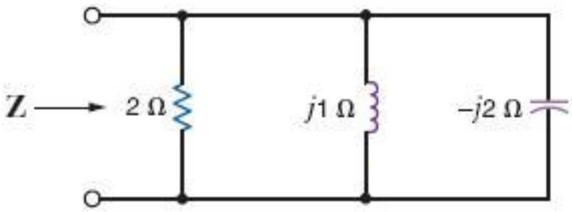
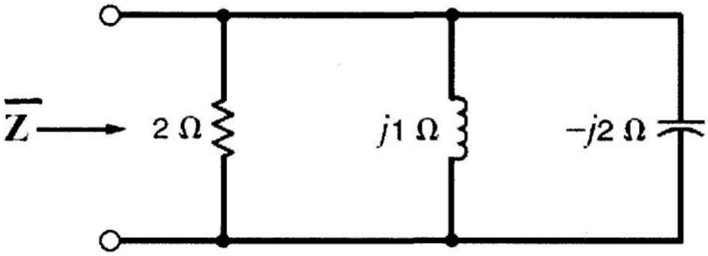


Figure P8.11

SOLUTION:



$$\bar{Z} = \left[-j2 \,\|\, j1\right] \| 2$$

$$\bar{Z} = \left[\frac{-j2(j1)}{-j2+j1}\right] \| 2$$

$$\bar{Z} = \frac{(2\angle 90^\circ)(2\angle 0^\circ)}{2\angle 90^\circ + 2\angle 0^\circ}$$

$$\bar{Z} = 1.414\angle 45^\circ \ \Omega$$

8.12 Find the impedance, Z, shown in Fig. P8.12 at a frequency of 60 Hz.

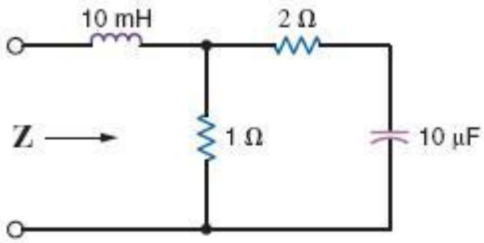
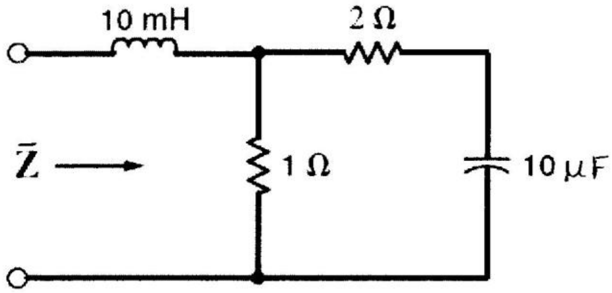


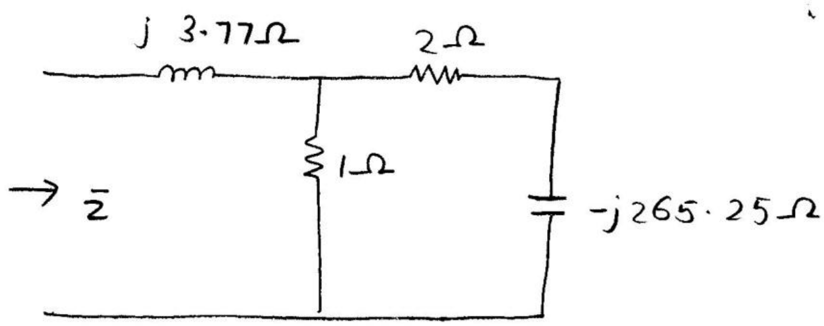
Figure P8.12

SOLUTION:



$$\bar{Z}_L = j(377)(10m) = j\,3.77\,\Omega$$

$$\bar{Z}_C = \frac{1}{j(377)(10\mu)} = -j\,265.25\,\Omega$$



$$\bar{Z} = \left[1 \| 2 - j\,265.25\right] + j\,3.77$$

$$\bar{Z} = \frac{1(2 - j265.25)}{1 + 2 - j265.25} + j3.77$$

$$\bar{Z} = 1 + j3.77\,\Omega$$

8.25 Find the frequency at which the circuit shown in Fig. P8.25 is purely resistive.

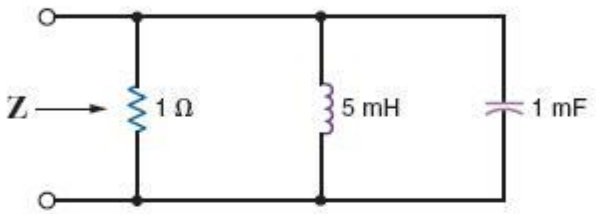
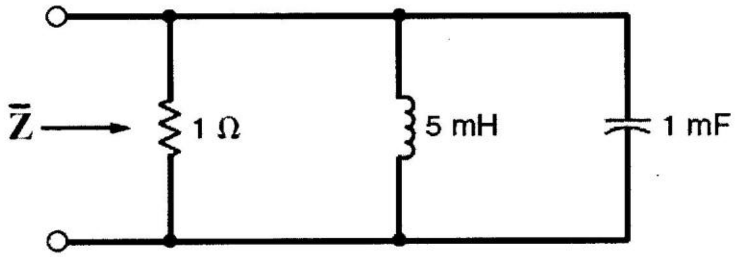


Figure P8.25

SOLUTION:



$\bar{Z} = R_{eq}$ Y

$eq = \qquad = \frac{1}{R} + \frac{1}{\bar{Z}_L} + \frac{1}{\bar{Z}_C}$

$\frac{1}{WL} = WC$

$W = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{5m\,(1m)}} = 447.21 \text{ rad/s}$

$F = \frac{\omega}{2\pi} = \frac{447.21}{2\pi}$

$F = 71.2 \text{ Hz}$

l
z

8.29 Draw the frequency-domain network and calculate $i(t)$ in the circuit shown in Fig. P8.29 if $v_s(t)$ is 15 sin $(10000t)$ V. Also, using a phasor diagram, show that $v_C(t) + v_R(t) = v_s(t)$.

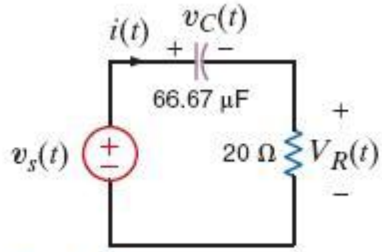
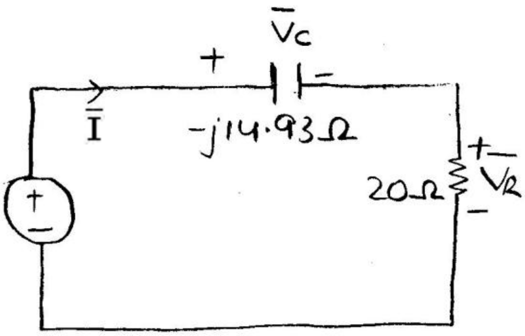


Figure P8.29

SOLUTION:

$\bar{V}_s = 15\angle -90^\circ V$



$$\bar{Z}_C = \frac{1}{j(1000)(66.67\mu)}$$

$$\bar{Z}_C = -j14.93\,\Omega$$

$$V_S(t) = 15 \sin 1000t \text{ V}$$
$$V_S(t) = 15 \cos(1000t - 90^\circ) \text{ V}$$

$$\bar{V}_S = 15\angle 90^\circ \text{ V}$$

$$\bar{I} = \frac{15\angle -90^\circ}{20 - j14.93}$$

$$\bar{I} = 0.6 \angle -53.26^\circ \text{ A}$$

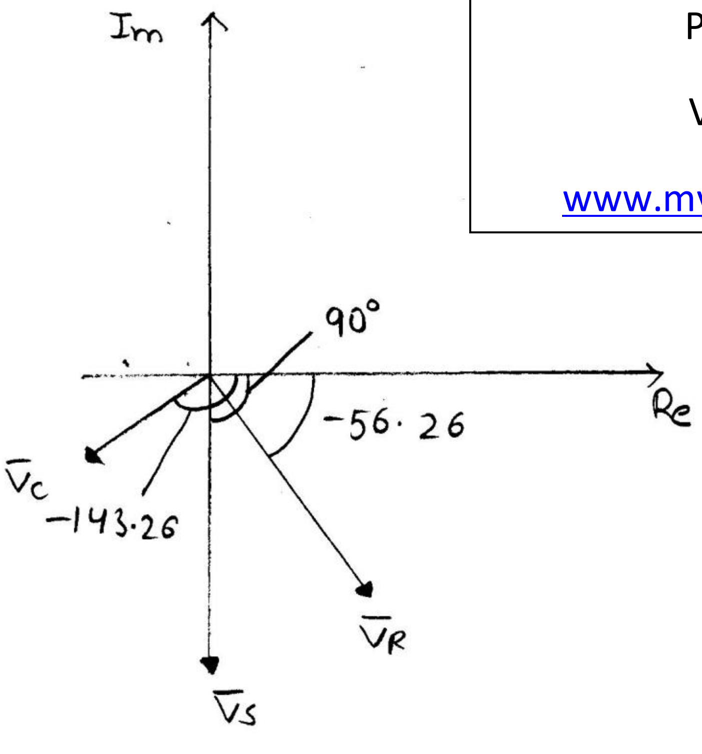
$$i(t) = 0.6 \cos(1000t - 53.26^\circ) \text{ A}$$

$$\bar{V}_C = (0.6 \angle -53.26^\circ)(-j14.93)$$

$$\bar{V}_C = 8.96 \angle -143.26^\circ \text{ V}$$

$$\bar{V}_R = (0.6 \angle -53.26^\circ)(20)$$

$$\bar{V}_R = 12 \angle -53.26^\circ \text{ V}$$



8.33 If $v_s(t) = 20 \cos 5t$ volts, find $v_0(t)$ in the network in Fig. P8.33.

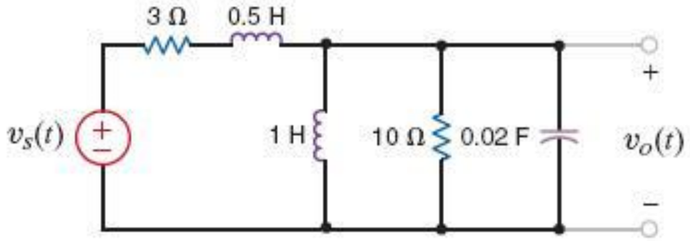


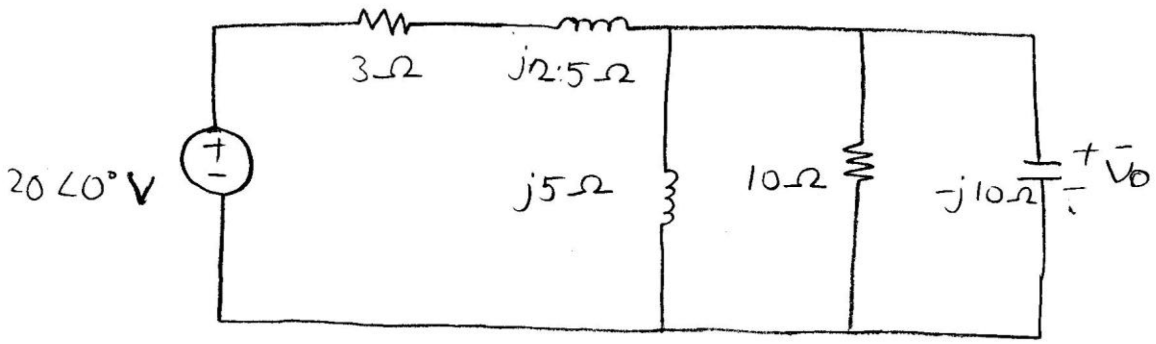
Figure P8.33

SOLUTION:

$$\bar{Z}_{L_1} = j\,5(0.5) = j\,2.5\ \Omega$$

$$\bar{Z}_{L_2} = j(5)(1) = j5\ \Omega$$

$$\bar{Z}_C = \frac{1}{j(5)(0.02)} = -j\,10\ \Omega$$



$$\bar{Z}_1 = (-j10 \parallel 10) \parallel j5$$

$$\bar{Z}_1 = \left[\frac{-j\,10(10)}{10-j10}\right] \parallel j5$$

$$\bar{Z}_1 = 7.07 \angle +45^\circ\ \Omega$$

$$\bar{V}_o = \left(\frac{7.07\angle+45^\circ}{7.07\angle+45^\circ+3+j2.5}\right)(20\angle 0^\circ)$$

$$\bar{V}_o = 12.9\angle 1.85^\circ \text{ V}$$

$$v_o(t) = 12.9\cos(5t+1.85^\circ)\text{ V}$$

8.35 Find $v(t)$ in the network in Fig. P8.35.

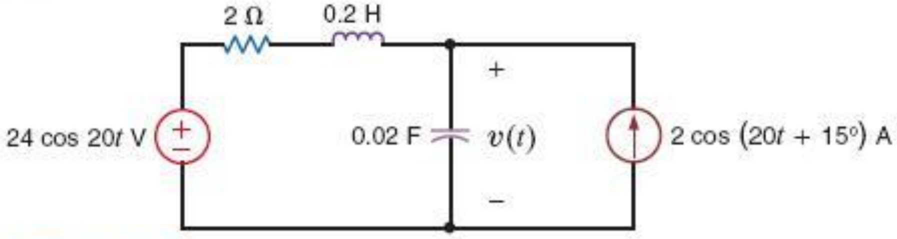
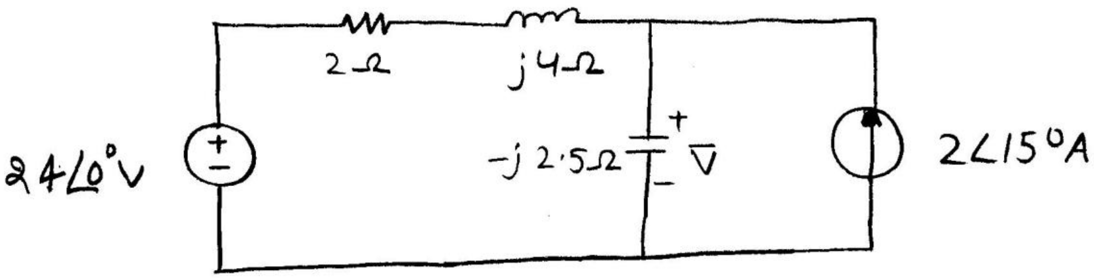


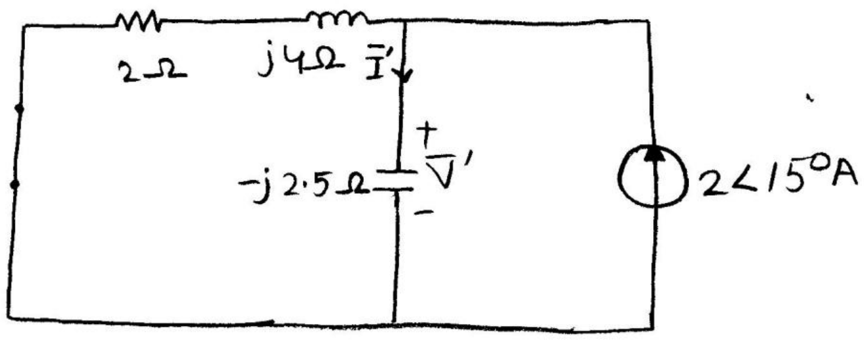
Figure P8.35

SOLUTION:

$$\bar{Z}_L = j(20)(0.2) = j4\,\Omega$$

$$\bar{Z}_C = \frac{1}{j(20)(0.02)} = -j2.5\,\Omega$$

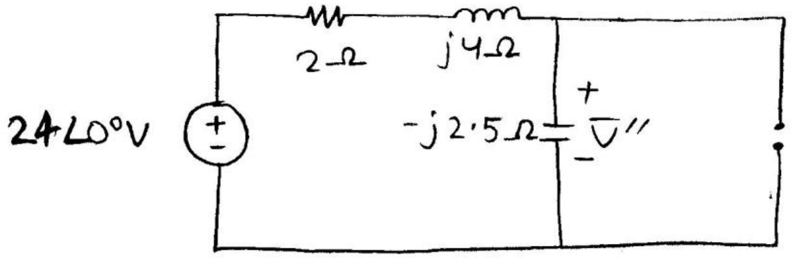




$$\bar{I}' = \left(\frac{2+j4}{2+j4-j2.5}\right)\left(2\angle 15^\circ\right)$$

$$\bar{V}' = (3.58\angle 41.57°)(-j2.5)$$

$$\bar{V}' = 8.94\angle -48.43° \text{ V}$$



$$\bar{V}'' = \left(\frac{-j2.5}{-j2.5+j4+2}\right)(20\angle 0°)$$

$$\bar{V}'' = 24\angle -126.87° \text{ V}$$

$$\bar{V} = \bar{V}' + \bar{V}'' = 8.94\angle -48.43° + 24\angle -126.87°$$

$$\bar{V} = 27.24\angle -108.1° \text{ V}$$

$$v(t) = 27.24\cos(20t - 108.1) \text{ V.}$$

8.38 Find $i_1(t)$ and $i_2(t)$ in the circuit in Fig. P8.38.

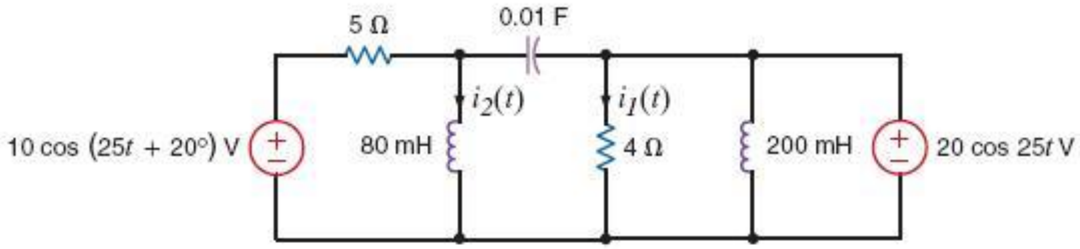
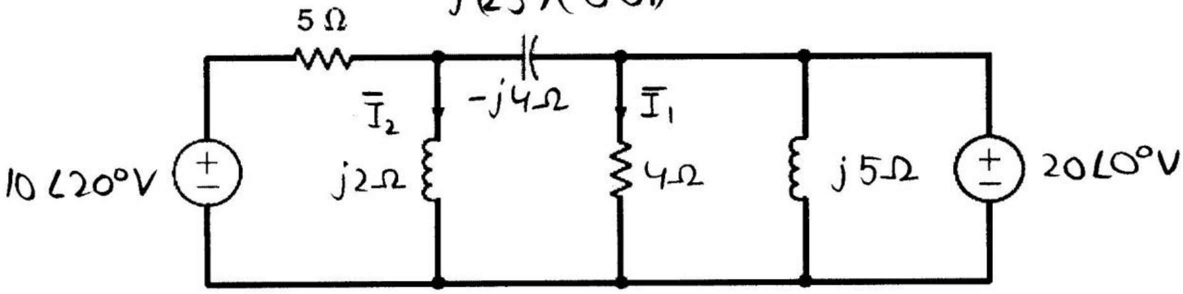
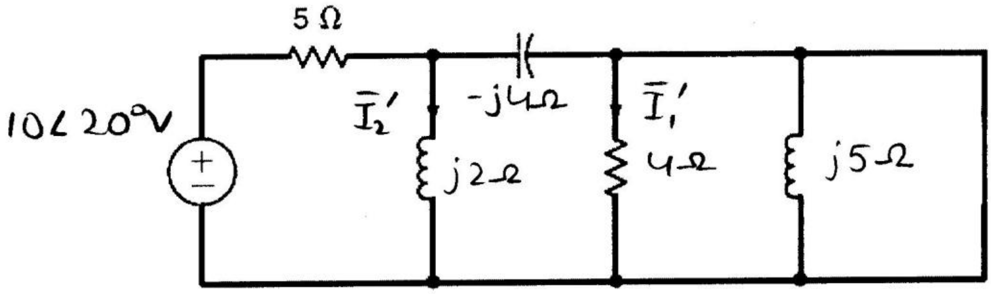


Figure P8.38

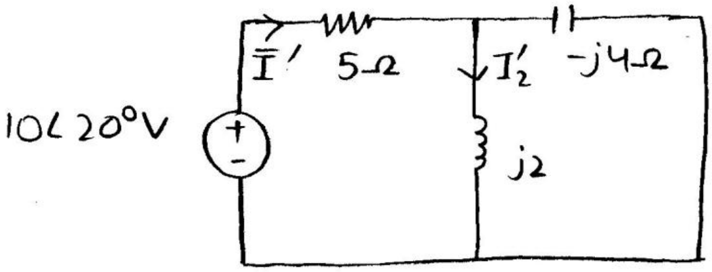
SOLUTION:

$$\bar{Z}_{L_1} = j(25)(80m) = j2\Omega$$
$$\bar{Z}_{L_2} = j(25)(80m) = j5\Omega$$
$$\bar{Z}_C = \frac{1}{j(25)(0.01)} = -j4\Omega$$





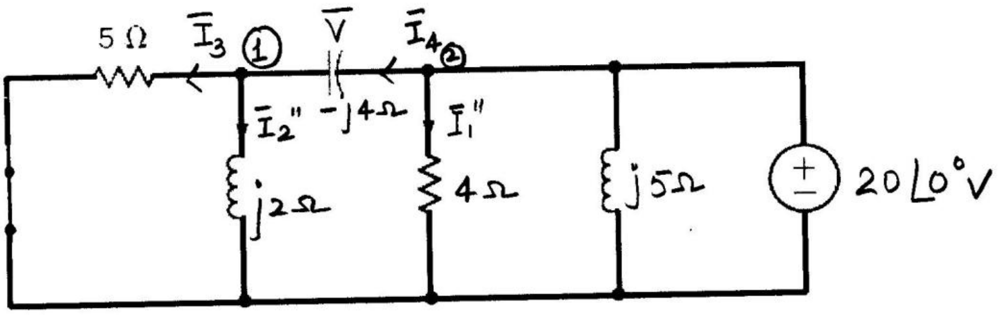
$\bar{I}_1' = 0A$, short across 4Ω.



$$\bar{I}' = \frac{10\angle 20^\circ}{(j2 \| -j4) + 5} = 1.56\angle -18.66^\circ \text{ A}$$

$$\bar{I}_2' = \left(\frac{-j4}{-j4+j2}\right)\left(1.56\angle -18.66^\circ\right)$$

$$\bar{I}_2' = 3.12\angle -18.66^\circ \text{ A}$$



$$\bar{I}_1'' = \frac{20\angle 0^\circ}{} = 5\angle 0^\circ \text{ A}$$

KCL at 1 : $\bar{I}_2'' + \bar{I}_3 = \bar{I}_4$

$$\frac{\bar{V}_1}{j2} + \frac{\bar{V}_1}{5} = \frac{\bar{V}_2 - \bar{V}_1}{-j4}$$

$$10\bar{V}_1 + j4\bar{V}_1 = -5\bar{V}_2 + 5\bar{V}_1$$

$$(5 + j4)\bar{V}_1 + 5\bar{V}_2 = 0$$

$$\bar{V}_2 = 20\angle 0^\circ \text{ V}$$

$$\bar{V}_1 = \frac{-5(20\angle 0^\circ)}{5 + j4}$$

$$\bar{V}_1 = 15.62 \angle 141.34^\circ \text{ V}$$

$$\bar{I}_2'' = \frac{\bar{V}_1}{j2} = \frac{15.62 \angle 141.34^\circ}{j2}$$

$$\bar{I}_2'' = 7.81 \angle 51.34^\circ \text{A}$$

$$\bar{I}_1 = \bar{I}_1' + \bar{I}_1'' = 0 + 5\angle 0^\circ$$

$$\bar{I}_1 = 5\angle 0^\circ \text{ A}$$

$$i_1(t) = 5\cos 25t \text{ A}$$

$$\bar{I}_2 = \bar{I}_2' + \bar{I}_2'' = 3.12 \angle -18.66^\circ + 7.81 \angle 51.34^\circ$$

$$\bar{I}_2 = 9.35 \angle 33.1^\circ \text{ A}$$

$$i_2(t) = 9.35 \cos(25t + 33.1^\circ) \text{ A}$$

8.39 Find $v_o(t)$ and $i_o(t)$ in the network in Fig. P8.39.

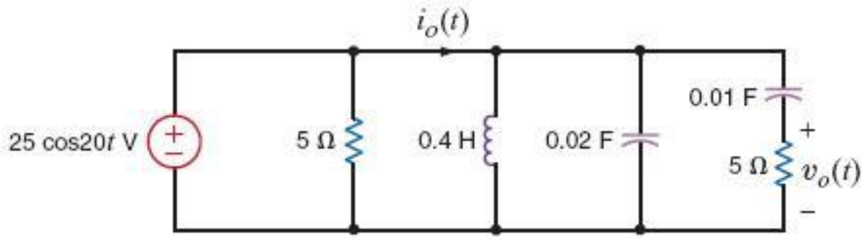


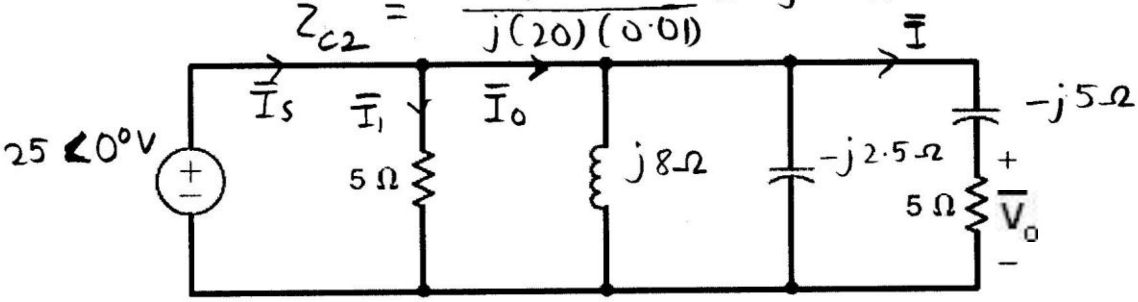
Figure P8.39

SOLUTION:

$$\bar{Z}_L = j(20)(0.4) = j8\,\Omega$$

$$\bar{Z}_{C1} = \frac{1}{j(20)(0.02)} = -j2.5\,\Omega$$

$$\bar{Z}_{C2} = \frac{1}{j(20)(0.01)} = -j5\,\Omega$$



$$\bar{I} = \frac{25\angle 0^\circ}{5-j5} = 3.54\angle 45^\circ\text{ A}$$

$$\bar{V}_o = (3.54\angle 45^\circ)(5)$$

$$\bar{V}_o = 17.68\angle 45^\circ\text{ V}$$

$$v_o(t) = 17.68\cos(20t + 45^\circ)\text{ V}$$

$$\bar{I}_1 = \frac{25\angle 0^\circ}{5} = 5\angle 0^\circ\text{A}$$

$$\bar{Z}_{eq} = [(5-j5)\,||\,-j2.5]\,||\,j8\,||\,5$$

$$\bar{Z}_{eq} = \left[\frac{(5-j5)(-j2.5)}{5-j5-j2.5}\right] \parallel j8 \parallel 5$$

$$\bar{Z}_{eq} = (1.96\angle -78.7^\circ \parallel j8) \parallel 5$$

$$\bar{Z}_{eq} = 2.57\angle -75.08^\circ \parallel 5$$

$$\bar{Z}_{eq} = 2.08\angle -51.4^\circ\ \Omega$$

$$\bar{I}_s = \frac{25\angle 0^\circ}{2.08\angle -51.4^\circ} = 12.02\angle 51.4^\circ\ A$$

$$\text{KCL:} \quad \bar{I}_s = \bar{I}_1 + \bar{I}_0$$

$$\bar{I}_0 = \bar{I}_s - \bar{I}_1$$

$$\bar{I}_0 = 12.02\angle 51.4^\circ - 5\angle 0^\circ$$

$$\bar{I}_0 = 9.72\angle 75.1^\circ\ A$$

$$i_0(t) = 9.72\cos(20t + 75.1^\circ)\ A$$

8.43 Find the voltage **V** shown in Fig. P8.43.

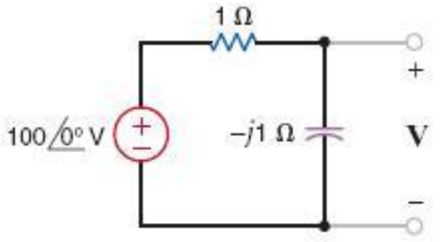
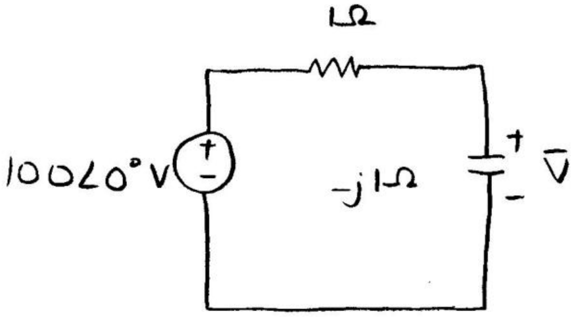


Figure P8.43

SOLUTION:



$$\bar{V} = \left(\frac{-j1}{1-j1}\right)(100\angle 0^\circ)$$

$$\bar{V} = 70.71\ \angle -45^\circ\ V$$

8.45 Find the frequency-domain current **I**, as shown in Fig. P8.45.

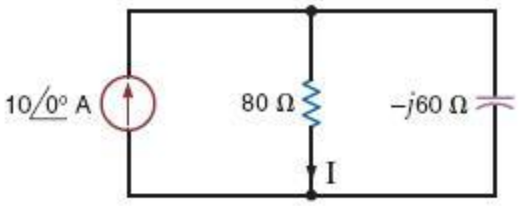
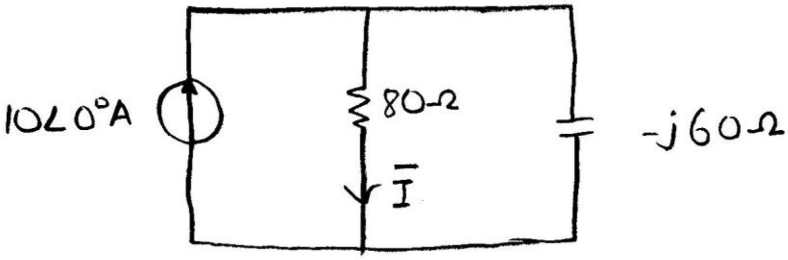


Figure P8.45

SOLUTION:



$$\bar{I} = \left(\frac{-j60}{80-j60}\right)(10\angle 0^\circ)$$

$$\bar{I} = 6\angle -53.13^\circ \text{ A}$$

8.46 Find the frequency-domain voltage $\mathbf{V}_o$, as shown in Fig. P8.46.

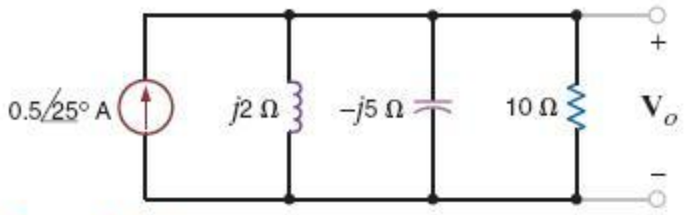
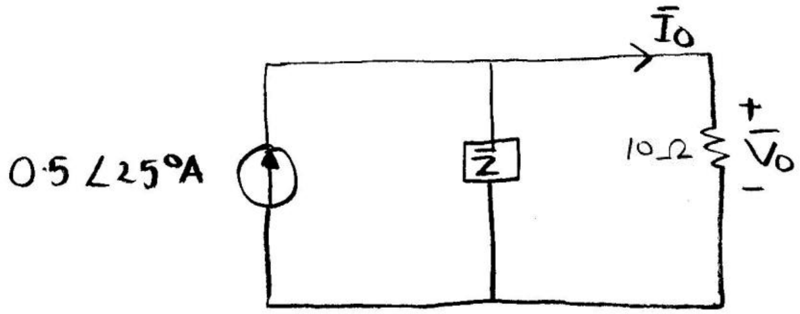


Figure P8.46

SOLUTION:



$$\bar{Z} = j2 \,||\, -j5 = \frac{j2(-j5)}{-j5 + j2}$$

$$\bar{Z} = 3.33 \angle 90° \ \Omega$$

$$\bar{I}_0 = \left(\frac{3.33 \angle 90°}{3.33\angle 90° + 10}\right)(0.5 \angle 25°)$$

$$\bar{I}_0 = 0.158 \angle 96.58° \text{ A}$$

$$\bar{V}_0 = 10\,(0.158 \angle 96.58°)$$

$$\bar{V}_0 = 1.58 \angle 96.58° \text{ V}$$

8.50 Find the frequency-domain voltage $\mathbf{V}_o$, as shown in Fig. P8.50.

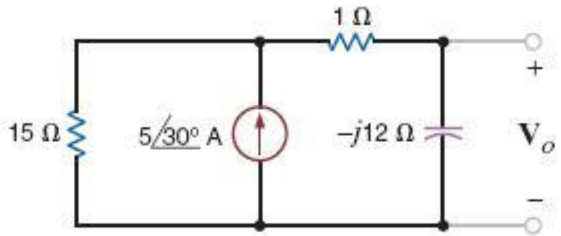
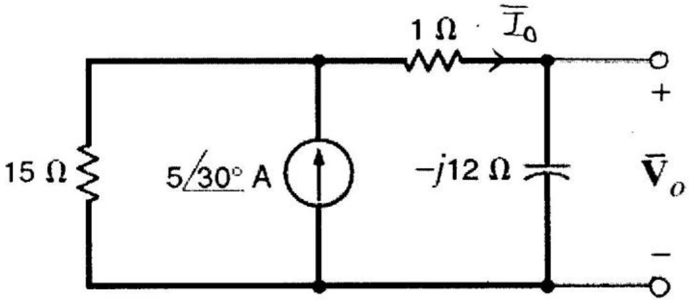


Figure P8.50

SOLUTION:



$$\bar{I}_0 = \left(\frac{15}{15+1-j12}\right)(5\angle 30^\circ)$$

$$\bar{I}_0 = 3.75\angle 66.87^\circ \text{ A}$$

$$\bar{V}_0 = (3.75\angle 66.87^\circ)(-j12)$$

$$\bar{V}_0 = 45\angle -23.13^\circ \text{ V}$$

8.54 Given the network in Fig. P8.54, determine the valve of $\mathbf{V}_o$ if $\mathbf{V}_s = 24\angle 0^\circ$ V.

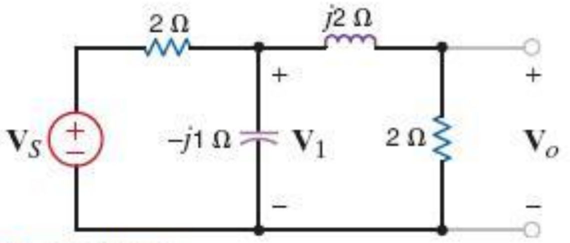
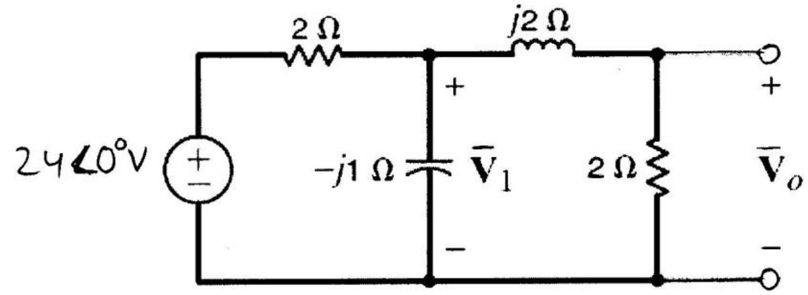
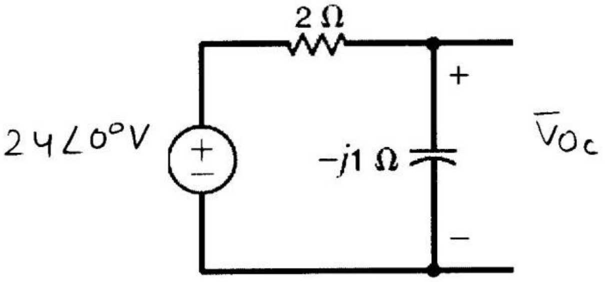


Figure P8.54

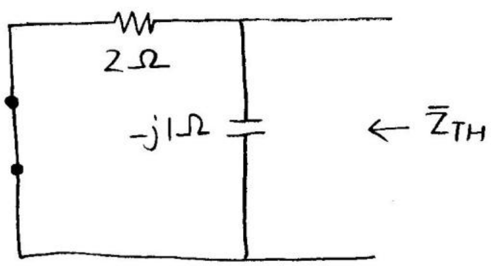
SOLUTION:





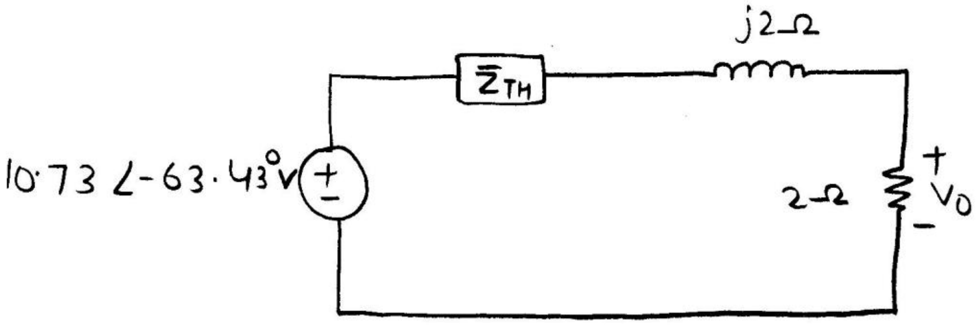
$$\bar{V}_{oc} = \left(\frac{-j1}{2-j1}\right)(24\angle 0^\circ)$$

$$\bar{V}_{oc} = 10.73\angle -63.43^\circ \text{ V}$$



$$\bar{Z}_{TH} = 2 \| -j1 = \frac{2(-j1)}{2-j1}$$

$$\bar{Z}_{TH} = 0.89 \angle -63.43^\circ \, \Omega$$



$$\bar{V}_0 = \left(\frac{2}{2+j2+0.89\angle -63.43^\circ}\right)(10.73\angle -63.43^\circ)$$

$$\bar{V}_0 = 8\angle -90.1^\circ \text{ V}$$

8.62 In the network in Fig. P8.62 $\mathbf{I}_o = 4\ \underline{/0^\circ}$ A, find $\mathbf{I}_x$.

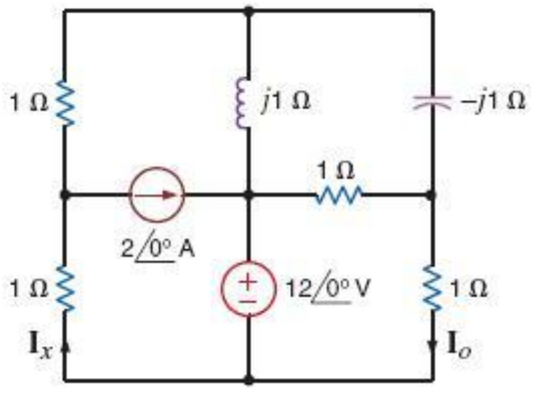
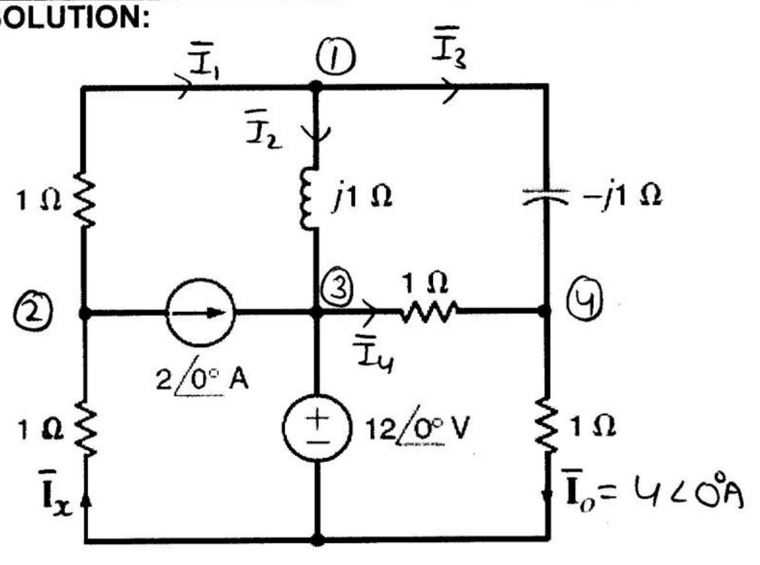


Figure P8.62

SOLUTION:



KCL at ① : $\bar{I}_1 = \bar{I}_2 + \bar{I}_3$

$$\frac{\bar{V}_2 - \bar{V}_1}{1} = \frac{\bar{V}_1 - \bar{V}_3}{j1} = \frac{\bar{V}_1 - \bar{V}_4}{-j1}$$

$$j1\,(\bar{V}_2 - \bar{V}_1) = \bar{V}_1 - \bar{V}_3 - \bar{V}_1 + \bar{V}_4$$

$$-j1\,\bar{V}_1 + j1\,\bar{V}_2 + \bar{V}_3 - \bar{V}_4 = 0$$

KCL at ②: $\bar{I}_1 + 2\angle 0° = \bar{I}_x$

$$\frac{\bar{V}_2 - \bar{V}_1}{1} + 2\angle 0° = \frac{-\bar{V}_2}{1}$$

$$\bar{V}_2 - \bar{V}_1 + 2\angle 0° = -\bar{V}_2$$

$$\bar{V}_1 - 2\bar{V}_2 = 2\angle 0°$$

KCL at ④: $\bar{I}_3 + \bar{I}_4 = \bar{I}_o$

$$\frac{\bar{V}_1 - \bar{V}_4}{j1} + \frac{\bar{V}_3 - \bar{V}_4}{1} = \frac{\bar{V}_4}{1}$$

$$\bar{V}_1 - \bar{V}_4 - j1(\bar{V}_3 - \bar{V}_4) = -j1\bar{V}_4$$

$$\bar{V}_1 - j1\bar{V}_3 + (-1+j2)\bar{V}_4 = 0$$

$$\bar{V}_4 = 1(4\angle 0°) = 4\angle 0° V$$

$$\bar{V}_1 + (-1+j2)\bar{V}_4 = 12\angle 90°$$

$$\bar{V}_1 = 12\angle 90° - 4\angle 0°(-1+j2)$$

$$\bar{V}_1 = 5.66\angle 45° V$$

$$\bar{V}_1 - 2\bar{V}_2 = 2\angle 0°$$

$$\bar{V}_2 = \frac{5.66\angle 45^\circ - 2\angle 0^\circ}{2}$$

$$\bar{V}_2 = 2.24\angle 63.43^\circ \text{ V}$$

$$\bar{I}_x = -1(2.24\angle 63.43^\circ)$$

$$\bar{I}_x = 2.24\angle -116.57^\circ \text{ A}$$

8.66 Using nodal analysis, find $\mathbf{I}_o$ in the circuit in Fig. P8.66.

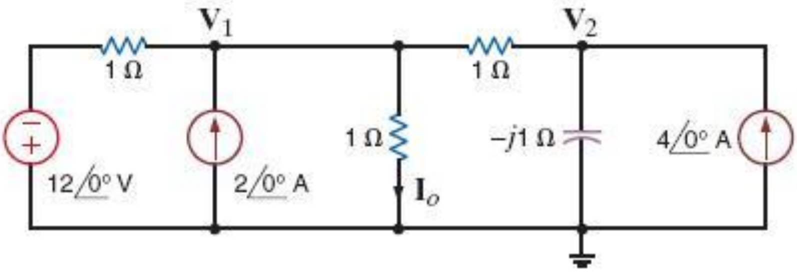
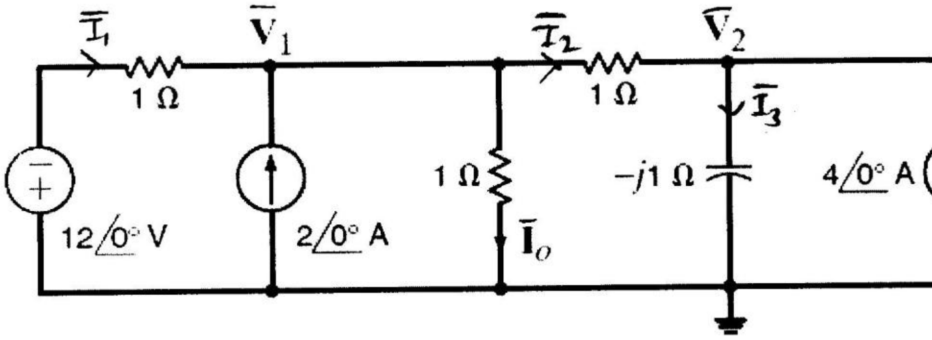


Figure P8.66

SOLUTION:



KCL at ① : $\bar{I}_1 + 2\angle 0° = \bar{I}_o + \bar{I}_2$

$$\frac{-12\angle 0° - \bar{V}_1}{1} + 2\angle 0° = \frac{\bar{V}_1}{1} + \frac{\bar{V}_1 - \bar{V}_2}{1}$$

$$-12\angle 0° - \bar{V}_1 + 2\angle 0° = \bar{V}_1 + \bar{V}_1 - \bar{V}_2$$

$$3\bar{V}_1 - \bar{V}_2 = 10\angle 180°$$

KCL at ② : $\bar{I}_2 + 4\angle 0° = \bar{I}_3$

$$\frac{\bar{V}_1 - \bar{V}_2}{1} + 4\angle 0° = \frac{\bar{V}_2}{-j1}$$

$$-j1(\bar{V}_1 - \bar{V}_2) - j1(4\angle 0°) = \bar{V}_2$$

$$-j1\,\bar{V}_1 + (-1 + j1)\,\bar{V}_2 = 4\angle 90°$$

$$3\bar{V}_1 - \bar{V}_2 = 10\angle 180^\circ$$

$$-j1\bar{V}_1 + (-1+j1)\bar{V}_2 = 4\angle 90^\circ$$

$$\bar{V}_1 = 3.23\angle -177.3^\circ \text{ V}$$

$$\bar{V}_2 = 0.55\angle -56.3^\circ \text{V}$$

$$\bar{I}_0 = \frac{\bar{V}_1}{1}$$

$$\bar{I}_0 = \frac{3.23\angle -177.3^\circ}{1}$$

$$\bar{I}_0 = 3.23\angle -177.3^\circ \text{ A}$$

8.68 Find $\mathbf{V}_o$ in the network in Fig. P8.68 using nodal analysis.

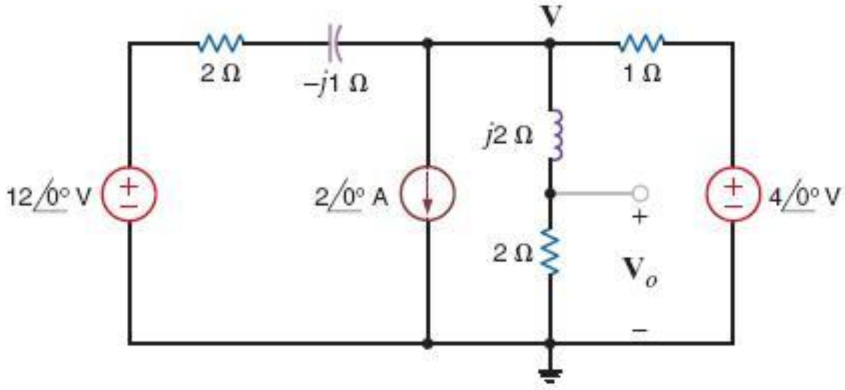
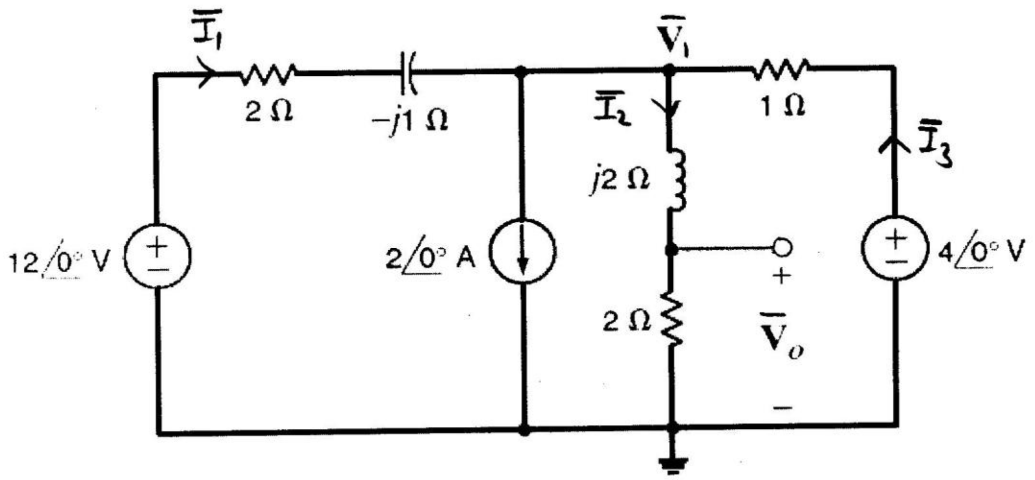


Figure P8.68

SOLUTION:



KCL at ①: $\bar{I}_1 + \bar{I}_3 = 2\angle 0^\circ + \bar{I}_2$

$$\frac{12\angle 0^\circ - \bar{V}_1}{2-j1} + \frac{4\angle 0^\circ - \bar{V}_1}{1} = 2\angle 0^\circ + \frac{\bar{V}_1}{2+j2}$$

$$\frac{\bar{V}_1}{2+j2} + \frac{\bar{V}_1}{2-j1} + \bar{V}_1 = \frac{12\angle 0^\circ}{2-j1} + 4\angle 0^\circ - 2\angle 0^\circ$$

$$\bar{V}_1 = \frac{7.21\angle 19.44^\circ}{1.65\angle -1.74^\circ}$$

$$\bar{V}_1 = 4.37 \angle 21.2^\circ \text{ V}$$

$$\bar{I}_2 = \frac{\bar{V}_1}{2+j2} = \frac{4.37 \angle 21.2^\circ}{2+j2}$$

$$\bar{I}_2 = 1.55 \angle -23.8^\circ \text{ A}$$

$$\bar{V}_o = 2(1.55 \angle -23.8^\circ)$$

$$\bar{V}_o = 3.1 \angle -23.8^\circ \text{ V}$$

8.71 Use nodal analysis to find $\mathbf{V}_o$ in the circuit in Fig. P8.71.

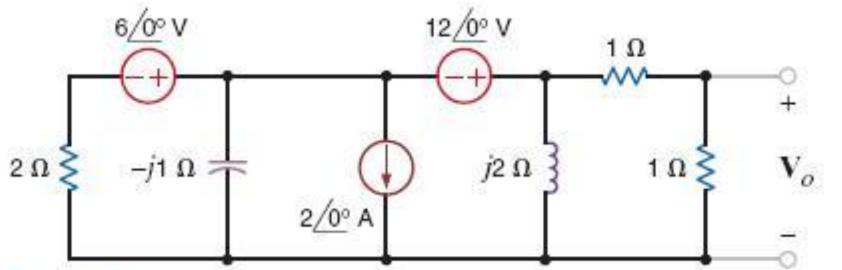
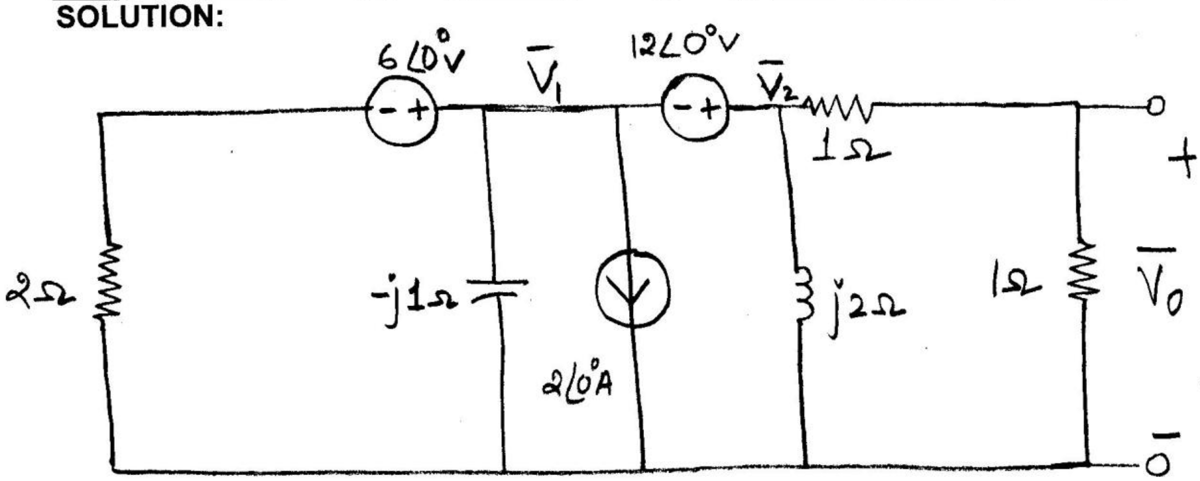


Figure P8.71

SOLUTION:



$$(\bar{V}_1 - 6)/2 + \bar{V}_1/(-j) + 2 = \bar{V}_2/(j2) + \bar{V}_2/(2)$$

$$\Rightarrow \bar{V}_1 \times (j-2) - 2j = \bar{V}_2 \times (1+j) \quad \text{——— eq 1}$$

$$\bar{V}_1 = \bar{V}_2 - 12 \quad \text{——— eq 2}$$

$$\bar{V}_0 = \bar{V}_2/(2) \quad \text{——— eq 3}$$

upon solving these

$$\bar{V}_2 = 8 - (14/3)j$$

hence $\bar{V}_0 = \bar{V}_2/(2) = 4 - j(7/3) = 4.6\angle -30.25^\circ$

8.77 Use mesh analysis to find $\mathbf{V}_o$ in the circuit shown in Fig. P8.77.

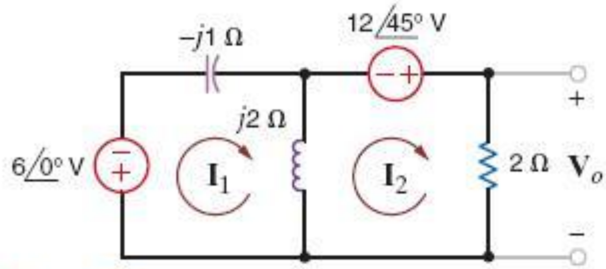
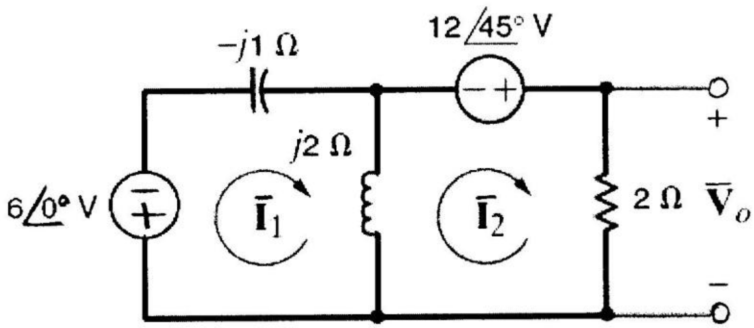


Figure P8.77

SOLUTION:



$\bar{I}_1 = \bar{I} + \bar{I}_2 \qquad \bar{I} = \bar{I}_1 - \bar{I}_2$

KVL left loop: $6\angle 0^\circ - j1\bar{I}_1 + j2\bar{I} = 0$

$j1\,\bar{I}_1 - j2(\bar{I}_1 - \bar{I}_2) = 6\angle 0^\circ$

$$\boxed{-j1\,\bar{I}_1 + j2\bar{I}_2 = 6\angle 0^\circ}$$

KVL right loop:

$2\bar{I}_2 - j2\bar{I} = 12\angle 45^\circ$

$-j2(\bar{I}_1 - \bar{I}_2) + 2\bar{I}_2 = 12\angle 45^\circ$

$$\boxed{-j2\,\bar{I}_1 + (2+j2)\,\bar{I}_2 = 2\angle 45^\circ}$$

$$-j1\bar{I}_1 + j2\bar{I}_2 = 6\angle 0^\circ$$

$$-j2\,\bar{I}_1 + (2+j2)\bar{I}_2 = 12\angle 45^\circ$$

$$\bar{I}_1 = 10.39\angle 125.26^\circ \text{A}$$

$$\bar{I}_2 = 3.25\angle 157.5^\circ \text{A}$$

$$\bar{V}_o = 2(3.25\angle 157.5^\circ)$$

$$\bar{V}_o = 6.5\angle 157.5^\circ$$

8.82 Using loop analysis, determine $\mathbf{V}_o$ in the network in Fig. P8.82.

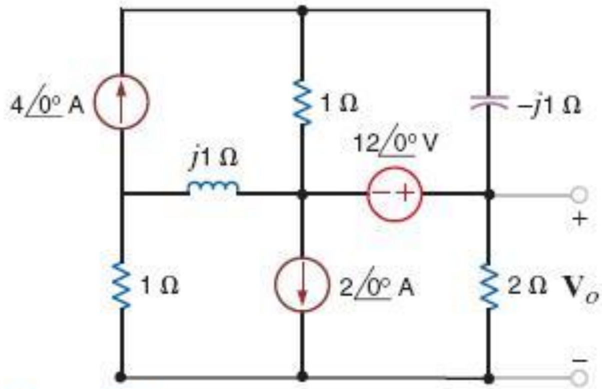
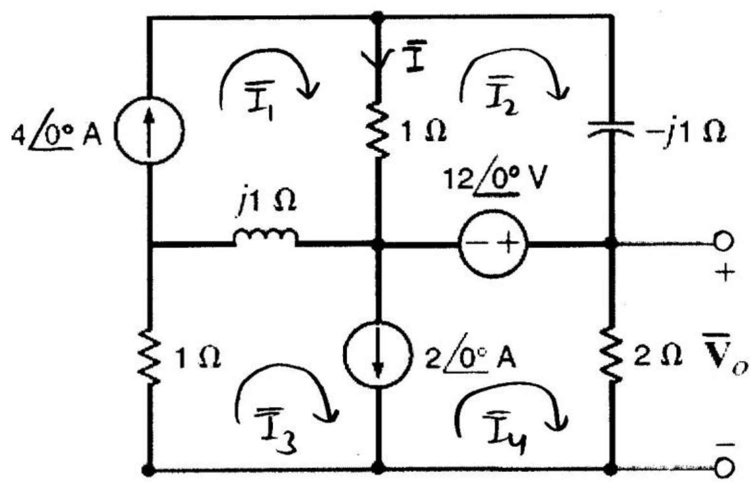


Figure P8.82

SOLUTION:



KCL: $\bar{I}_1 = \bar{I} + \bar{I}_2$

$\bar{I} = \bar{I}_1 - \bar{I}_2$

KCL: $\bar{I}_3 = \bar{I}' + \bar{I}_1$

$\bar{I}' = \bar{I}_3 - \bar{I}_1$

KVL: $12\angle 0° + 1(-\bar{I}) - j1(\bar{I}_2) = 0$

$$-(\bar{I}_1 - \bar{I}_2) - j1\bar{I}_2 = 12\angle 180°$$

$$-\bar{I}_1 + (1-j1)\bar{I}_2 = 12\angle 180^\circ$$

$$\bar{I}_1 = 4\angle 0^\circ \text{A}$$

$$(1-j1)\bar{I}_2 = 12\angle 180^\circ + 4\angle 0^\circ$$

$$\bar{I}_2 = 5.66\angle -135^\circ \text{ A}$$

$$\text{KVL: } 1(-\bar{I}) - j1\bar{I}_2 + 2\bar{I}_4 + 1(\bar{I}_3) + j1\bar{I}' = 0$$

$$-(\bar{I}_1 - \bar{I}_2) - j1\bar{I}_2 + 2\bar{I}_4 + \bar{I}_3 + j1(\bar{I}_3 - \bar{I}_1) = 0$$

$$(-1-j1)\bar{I}_1 + (1-j1)\bar{I}_2 + (1+j1)\bar{I}_3 + 2\bar{I}_4 = 0$$

$$(-1-j1)(4\angle 0^\circ) + (1-j1)(5.66\angle -135^\circ) + (1+j1)\bar{I}_3 + 2\bar{I}_4 = 0$$

$$(1+j1)\bar{I}_3 + 2\bar{I}_4 = 12.65\angle 18.43^\circ$$

$$\text{KCL: } \bar{I}_4 + 2\angle 0^\circ = \bar{I}_3$$

$$\bar{I}_3 - \bar{I}_4 = 2\angle 0^\circ$$

$$(1+j1)\bar{I}_3 + 2\bar{I}_4 = 12.65\angle 18.43^\circ$$

$$\bar{I}_3 - \bar{I}_4 = 2\angle 0^\circ$$

$$\bar{I}_3 = 5.22\angle -4.4^\circ \text{ A}$$

$$\bar{I}_4 = 3.23\angle -7.13^\circ \text{ A}$$

$$\bar{V}_0 = 2\bar{I}_4 = 2(3.23 \angle -7.13°)$$

$$\bar{V}_0 = 6.46 \angle -7.13° \text{ V}$$

8.87 Find $\mathbf{V}_o$ in the network in Fig. P8.87.

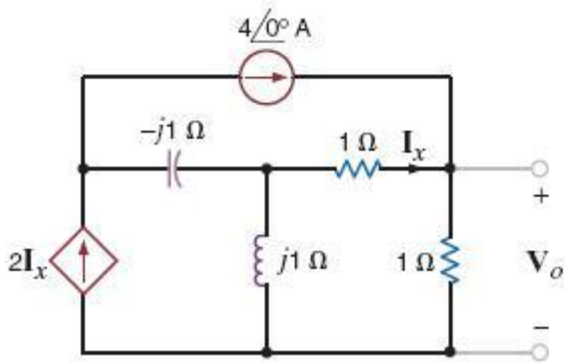
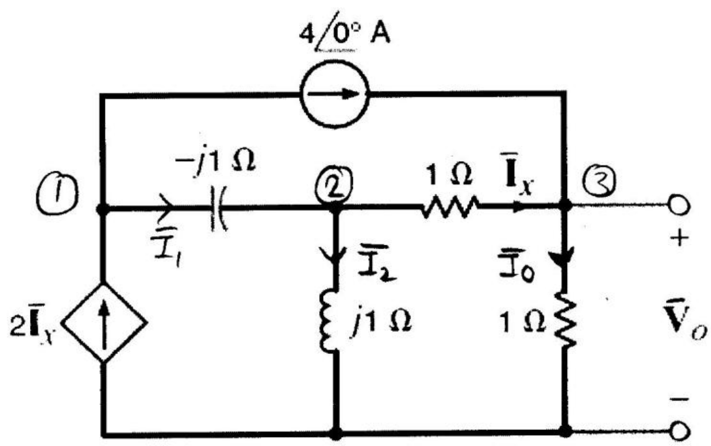


Figure P8.87

SOLUTION:



KCL at ① : $2\bar{I}_x = 4\angle 0^\circ + \bar{I}_1$

$$\bar{I}_x = \frac{\bar{V}_2 - \bar{V}_3}{1}$$

$$2\left[\frac{\bar{V}_2 - \bar{V}_3}{1}\right] = 4\angle 0^\circ + \frac{\bar{V}_1 - \bar{V}_2}{-j1}$$

$$-j2\left[\bar{V}_2 - \bar{V}_3\right] = -j1\,(4\angle 0^\circ) + \bar{V}_1 - \bar{V}_2$$

$$\bar{V}_1 + (-1+j2)\,\bar{V}_2 - j2\,\bar{V}_3 = j1(4\angle 0^\circ)$$

KCL at ②: $\bar{I}_1 = \bar{I}_x + \bar{I}_2$

$$\frac{\bar{V}_1 - \bar{V}_2}{-j1} = \frac{\bar{V}_2 - \bar{V}_3}{1} + \frac{\bar{V}_2}{j1}$$

$$\bar{V}_1 - \bar{V}_2 = -j1(\bar{V}_2 - \bar{V}_3) - \bar{V}_2$$

$$\bar{V}_1 + j1\bar{V}_2 - j1\bar{V}_3 = 0$$

KCL at ③ : $\bar{I}_x + 4\angle 0° = \bar{I}_0$

$$\frac{\bar{V}_2 - \bar{V}_3}{1} + 4\angle 0° = \frac{\bar{V}_3}{1}$$

$$\bar{V}_2 - 2\bar{V}_3 = 4\angle 180°$$

$$\bar{V}_1 + (-1 + j2)\bar{V}_2 - j2\bar{V}_3 = 4\angle 90°$$

$$\bar{V}_1 + j1\bar{V}_2 - j1\bar{V}_3 = 0$$

$$\bar{V}_2 - 2\bar{V}_3 = 4\angle 180°$$

$$\bar{V}_1 = 2.53\angle 161.57° \text{V}$$

$$\bar{V}_2 = 5.37\angle -63.43° \text{V}$$

$$\bar{V}_3 = 4\angle -36.87° \text{V}$$

$\bar{V}_0 = \bar{V}_3$

$$\bar{V}_0 = 4\angle -36.87° \text{V}$$

8.88 Find $\mathbf{V}_o$ in the circuit in Fig. P8.88.

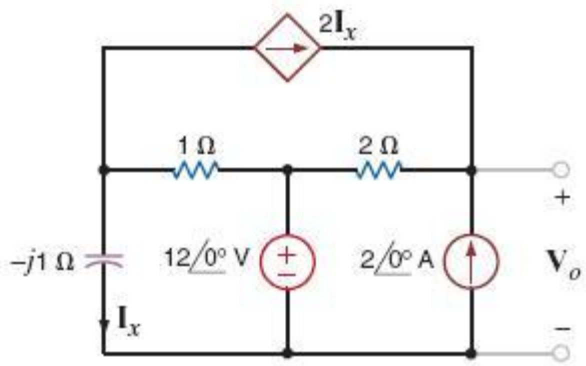
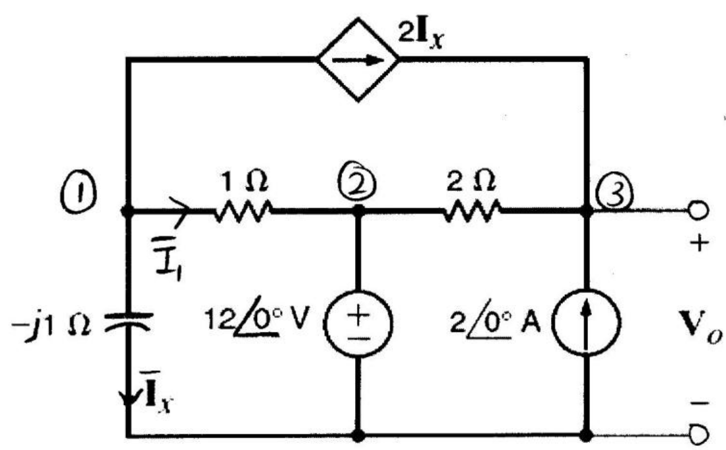


Figure P8.88

SOLUTION:



KCL at ①: $\quad 2\bar{I}_x + \bar{I}_1 + \bar{I}_x = 0$

$$\bar{I}_x = \frac{\bar{V}_1}{-j1}$$

$$2\left[\frac{\bar{V}_1}{-j1}\right] + \frac{\bar{V}_1 - \bar{V}_2}{1} + \frac{\bar{V}_1}{-j1} = 0$$

$$2\bar{V}_1 - j1(\bar{V}_1 - \bar{V}_2) + \bar{V}_1 = 0$$

$$(3 - j1)\bar{V}_1 + j1\bar{V}_2 = 0$$

$$\bar{V}_2 = 12\angle 0° V$$

$$(3 - j1)\bar{V}_1 + j1(12\angle 0°) = 0$$

$$\bar{V}_1 = 3.8\angle 71.6° V$$

KCL at 3: $\bar{I}_2 + 2\bar{I}_x + 2\angle 0° = 0$

$$\frac{\bar{V}_2 - \bar{V}_3}{2} + 2\left[\frac{\bar{V}_1}{-j1}\right] + 2\angle 0° = 0$$

$$\frac{12\angle 0° - \bar{V}_3}{2} + 2\left[\frac{3.8\angle -71.6°}{-j1}\right] + 2\angle 0° = 0$$

$$\bar{V}_3 = 30.8\angle 8.96° V$$

$$\bar{V}_0 = \bar{V}_3$$

$$\bar{V}_3 = 30.8\angle 8.96° V$$

8.100 Use Thévenin's theorem to find $\mathbf{V}_o$ in the network in Fig. P8.100.

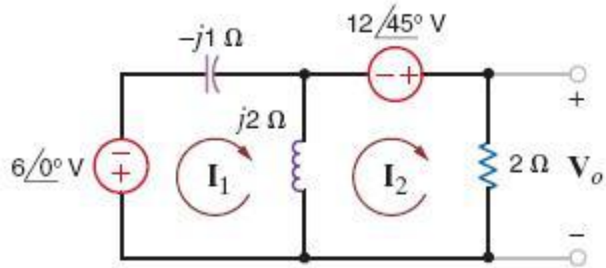
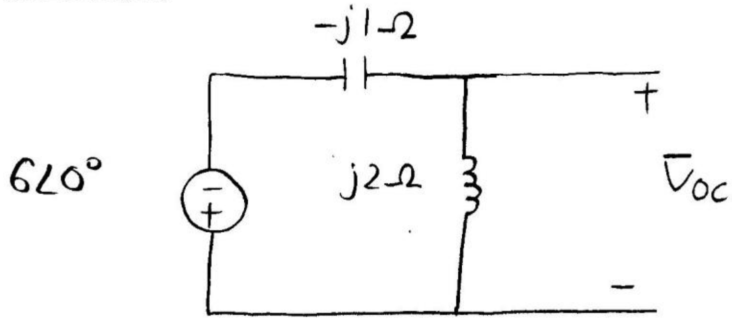
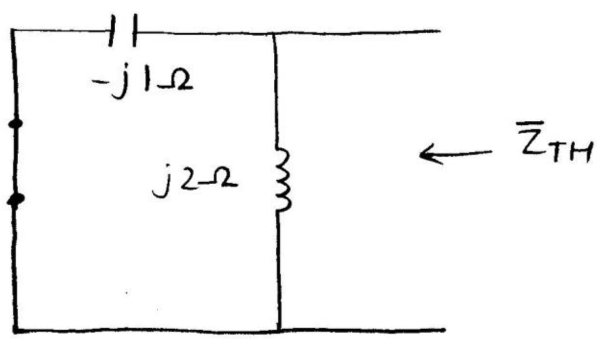


Figure P8.100

SOLUTION:

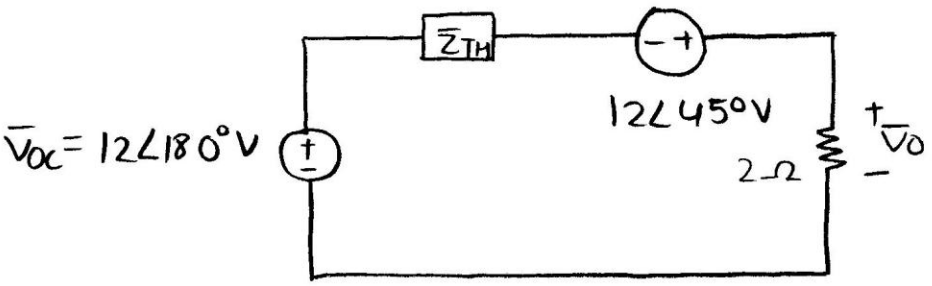


$$\bar{V}_{OC} = \left(\frac{j2}{-j1+j2}\right)(-6\angle 0°) = 12\angle 180° \text{V}$$



$$\bar{Z}_{TH} = j2 \,||\, -j1 = \frac{j2(-j1)}{j2-j1}$$

$$\bar{Z}_{TH} = 2\angle -90° \ \Omega$$



$$\bar{V}_o = \left(\frac{2}{2+2\angle -90^\circ}\right)\left(12\angle 180^\circ + 12\angle 45^\circ\right)$$

$$\bar{V}_o = 6.5\angle 157.5^\circ \text{ V}$$

8.101 Find V_o in Fig. P8.101 using Thévenin's theorem.

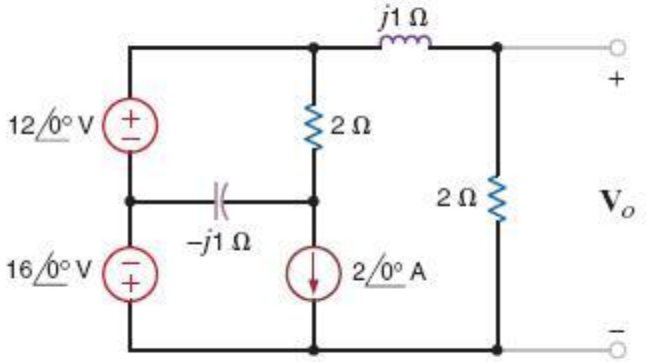
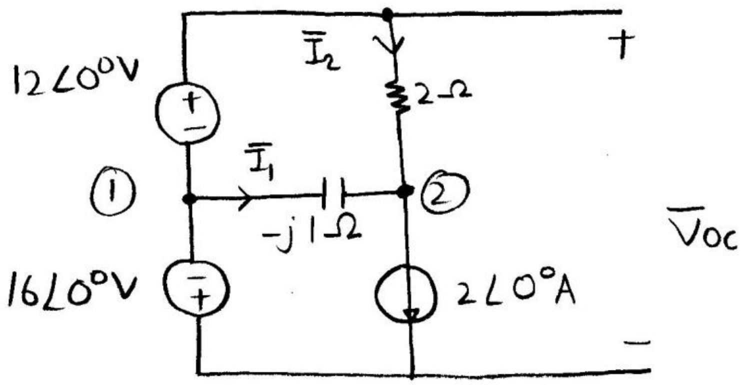


Figure P8.101

SOLUTION:



KCL at ② : $\bar{I}_1 + \bar{I}_2 = 2\angle 0^\circ$

$$\frac{\bar{V}_1 - \bar{V}_2}{-j1} + \frac{\bar{V}_{oc} - \bar{V}_2}{2} = 2\angle 0^\circ$$

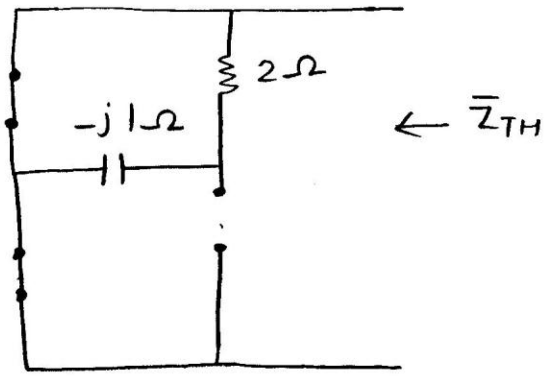
$$\frac{\bar{V}_1}{-j1} + \left(\frac{1}{j1} - \frac{1}{2}\right)\bar{V}_2 + \frac{\bar{V}_{oc}}{2} = 2\angle 0^\circ$$

$$\bar{V}_1 = -16\angle 0^\circ \mathrm{V}$$

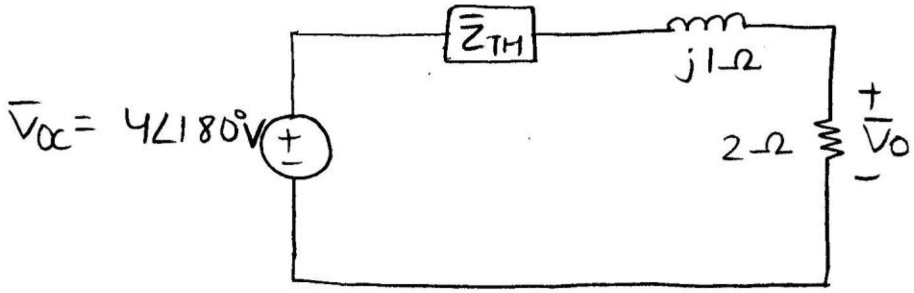
$$\bar{V}_{oc} - \bar{V}_1 = 12\angle 0^\circ$$

$$\bar{V}_{OC} = 12\angle 0^\circ + 16\angle 180^\circ$$

$$\bar{V}_{OC} = 4\angle 180^\circ \text{ V}$$



$$\bar{Z}_{TH} = 0\,\Omega$$



$$\bar{V}_O = \left(\frac{2}{2+j1+0}\right)(4\angle 180^\circ)$$

$$\bar{V}_O = 3.6\angle 153.4^\circ \text{ V}$$

8.107 Find $\mathbf{V}_o$ in the network in Fig. P8.107 using Thévenin's theorem.

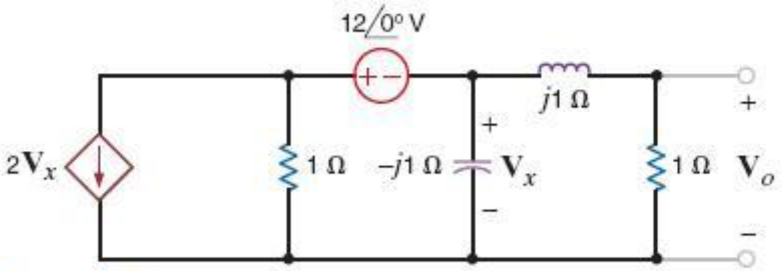
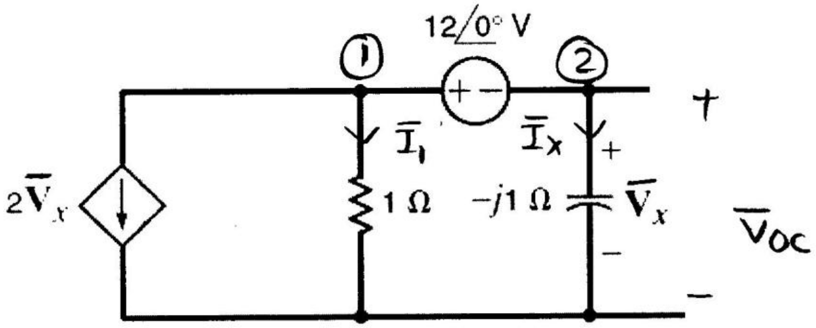


Figure P8.107

SOLUTION:



KCL at reference node:

$$2\bar{V}_x + \bar{I}_1 + \bar{I}_x = 0$$

$$\bar{V}_x = \bar{V}_2$$

$$2\bar{V}_2 + \frac{\bar{V}_1}{1} + \frac{\bar{V}_2}{-j1} = 0$$

$$-j2\bar{V}_2 - j1\bar{V}_1 + \bar{V}_2 = 0$$

$$-j1\bar{V}_1 + (1-j2)\bar{V}_2 = 0$$

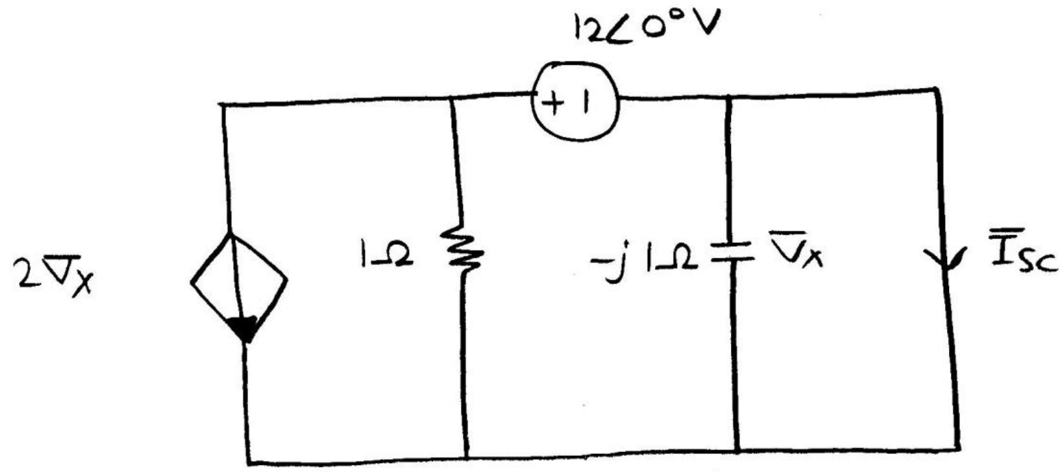
$$\bar{V}_1 - \bar{V}_2 = 12\angle 0^\circ$$

$$\bar{V}_1 = 8.49 \angle 8.13^\circ \text{ V}$$

$$\bar{V}_2 = 3.8 \angle 161.57^\circ \text{ V}$$

$$\bar{V}_{OC} = \bar{V}_2$$

$$\bar{V}_{OC} = 3.8 \angle 161.57^\circ \text{ V}$$



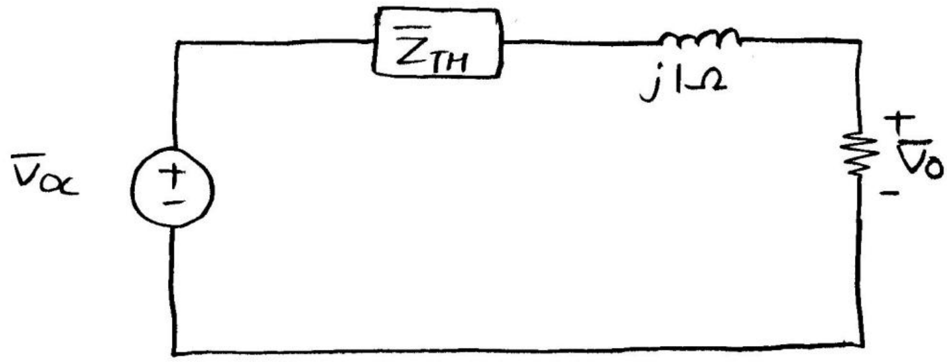
$$\bar{V}_x = 0\text{V}$$

$$\frac{12\angle 0^\circ}{1} + \bar{I}_{SC} = 0$$

$$\bar{I}_{SC} = 12\angle 180^\circ \text{ A}$$

$$\bar{Z}_{TH} = \frac{\bar{V}_{OC}}{\bar{I}_{SC}} = \frac{3.8\angle 161.57^\circ}{12\angle 180^\circ}$$

$$\bar{Z}_{TH} = 0.32 \angle -18.43^\circ \,\Omega$$



$$\bar{V}_0 = \left(\frac{1}{1+j1+0.32\angle -18.43^\circ}\right)(3.8\angle 161.57^\circ)$$

$$\bar{V}_0 = 2.4\angle 127^\circ \text{V}$$

8.108 Find the Thévenin's equivalent for the network in Fig. P8.108 at terminals A-B.

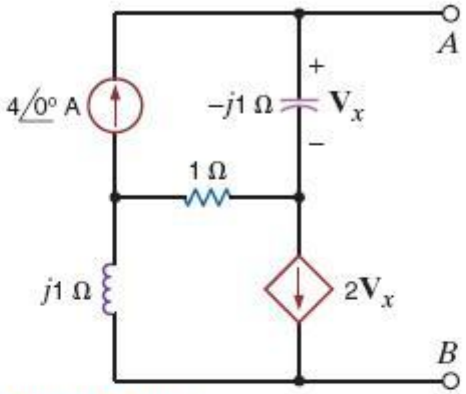
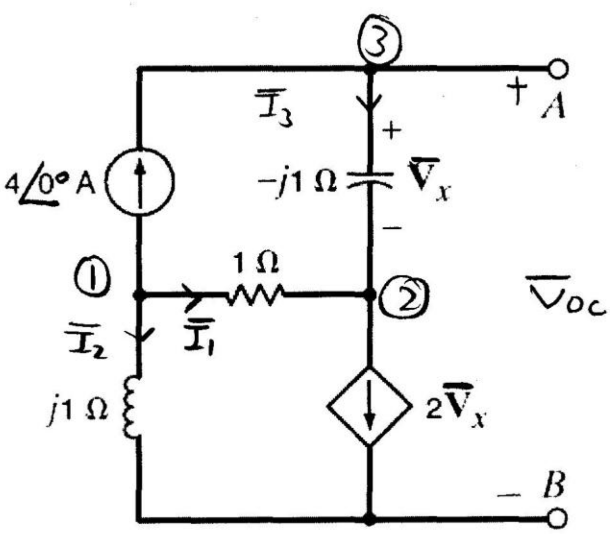


Figure P8.108

SOLUTION:



KCL at ① : $4\angle 0° + \bar{I}_1 + \bar{I}_2 = 0$

$$\frac{\bar{V}_1 - \bar{V}_2}{1} + \frac{\bar{V}_1}{j1} = -4\angle 0°$$

$$j1(\bar{V}_1 - \bar{V}_2) + \bar{V}_1 = j1(-4\angle 0°)$$

$$(1+j1)\bar{V}_1 - j1\bar{V}_2 = 4\angle -90°$$

KCL at ② : $\bar{I}_3 + \bar{I}_1 = 2\bar{V}_x$

$$\bar{V}_x = \bar{V}_{oc} - \bar{V}_2$$

$$\frac{\bar{V}_{oc} - \bar{V}_2}{-j1} + \frac{\bar{V}_1 - \bar{V}_2}{1} = 2[\bar{V}_{oc} - \bar{V}_2]$$

$$\bar{V}_{oc} - \bar{V}_2 - j1(\bar{V}_1 - \bar{V}_2) = -j2[\bar{V}_{oc} - \bar{V}_2]$$

$$-j1\bar{V}_1 + (-1-j1)\bar{V}_2 + (1+j2)\bar{V}_{oc} = 0$$

KCL at 3: $\bar{I}_3 = 4\angle 0°$

$$\frac{\bar{V}_{oc} - \bar{V}_2}{-j1} = 4\angle 0°$$

$$-\bar{V}_2 + V_{oc} = 4\angle -90°$$

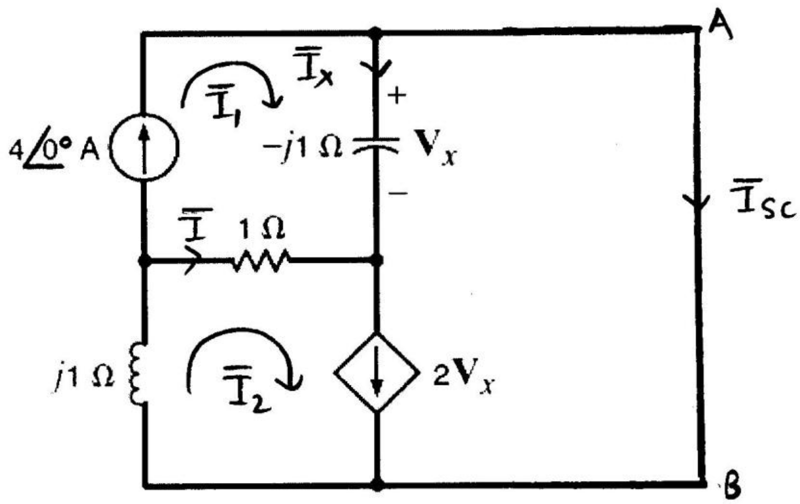
$$(1+j1)\bar{V}_1 - j1\bar{V}_2 = 4\angle -90°$$

$$-j1\bar{V}_1 + (-1-j1)\bar{V}_2 + (1+j2)\bar{V}_{oc} = 0$$

$$-\bar{V}_2 + \bar{V}_{oc} = 4\angle -90°$$

$$\bar{V}_1 = 8\angle 180° \text{ V}$$
$$\bar{V}_2 = 8.94\angle 116.6° \text{ V}$$

$$\bar{V}_{oc} = 5.66\angle 135° \text{ V}$$



KCL: $\bar{I}_2 = \bar{I} + \bar{I}_1$

$$\bar{I} = \bar{I}_2 - \bar{I}_1$$

KCL: $4\angle 0° = \bar{I}_x + \bar{I}_{sc}$

$$\bar{I}_x = 4\angle 0° - \bar{I}_{sc}$$

KVL: $1(\bar{I}) - j1(-\bar{I}_x) + j1(\bar{I}_2) = 0$

$$\bar{I}_2 - \bar{I}_1 + j1(4\angle 0° - \bar{I}_{sc}) + j1\,\bar{I}_2 = 0$$

$$-\bar{I}_1 + (1+j1)\,\bar{I}_2 - j1\bar{I}_{sc} = 4\angle -90°$$

KCL: $2\bar{V}_x + \bar{I}_{sc} = \bar{I}_2$

$$\bar{V}_x = -j1\,(4\angle 0° - \bar{I}_{sc})$$

$$-j2(4\angle 0° - \bar{I}_{sc}) + \bar{I}_{sc} = \bar{I}_2$$

$$-\bar{I}_2 + (1+j2)\,\bar{I}_{sc} = 8\angle 90^\circ$$

$$\bar{I}_1 = 4\angle 0^\circ \text{ A}$$

$$(1+j1)\,\bar{I}_2 - j1\,\bar{I}_{sc} = 5.66\angle -45^\circ$$

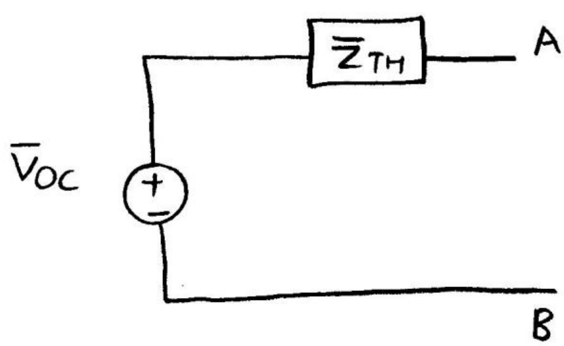
$$-\bar{I}_2 + (1+j2)\,\bar{I}_{sc} = 8\angle 90^\circ$$

$$\bar{I}_2 = 2.53\angle 71.6^\circ \text{ A}$$

$$\bar{I}_{sc} = 2.53\angle 18.43^\circ \text{ A}$$

$$\bar{Z}_{TH} = \frac{\bar{V}_{oc}}{\bar{I}_{sc}} = \frac{5.66\angle 135^\circ}{2.53\angle 18.43^\circ}$$

$$\bar{Z}_{TH} = 2.24\angle 116.57^\circ\ \Omega$$



8.114 Calculate the Thévenin equivalent impedance Z_{Th} in the circuit shown in Fig. P8.114.

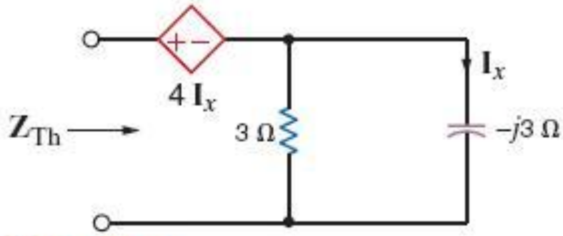
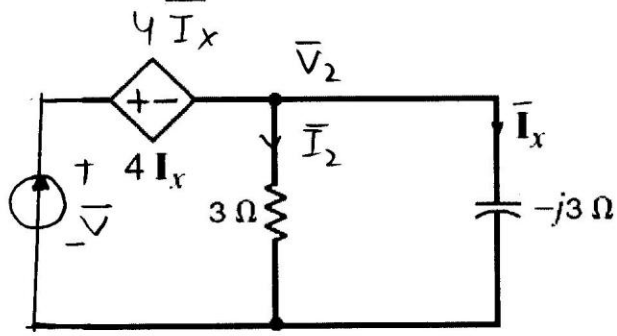


Figure P8.114

SOLUTION:

$\bar{I} = 1\angle 0° A$



KCL at ②: $1\angle 0° = \bar{I}_2 + \bar{I}_x$

$$\frac{\bar{V}_2}{3} + \frac{\bar{V}_2}{-j3} = 1\angle 0°$$

$$-j1\bar{V}_2 + \bar{V}_2 = -j3(1\angle 0°)$$

$$\bar{V}_2(1-j1) = 3\angle -90°$$

$$\bar{V}_2 = 2.12\angle -45° \text{ V}$$

$$\bar{I}_2 = \frac{\bar{V}_2}{3} = \frac{2.12\angle -45°}{3} = 0.707\angle -45° \text{A}$$

$$\bar{I}_x = \frac{\bar{V}_2}{-j3} = \frac{2.12\angle -45°}{-j3} = 0.707\angle 45° \text{A}$$

KVL: $\bar{V} = 4\bar{I}_x + 3\bar{I}_2$

$$\bar{V} = 4(0.707\angle 45^\circ) + 3(7.07\angle -45^\circ)$$

$$\bar{V} = 3.54\angle 8.13^\circ \text{ V}$$

$$\bar{Z}_{TH} = \frac{\bar{V}}{\bar{I}} = \frac{3.54\angle 8.13^\circ}{1\angle 0^\circ}$$

$$\bar{Z}_{TH} = 3.54\angle 8.13^\circ \ \Omega$$

8.115 Find the Thévenin equivalent for the network in Fig. P8.115 at terminals *A-B*.

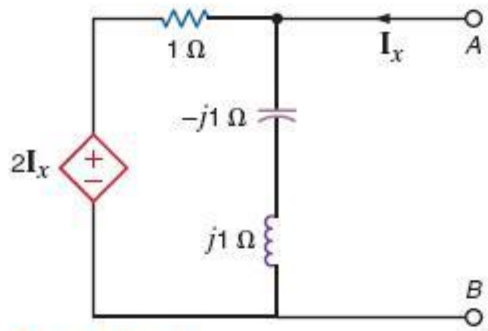
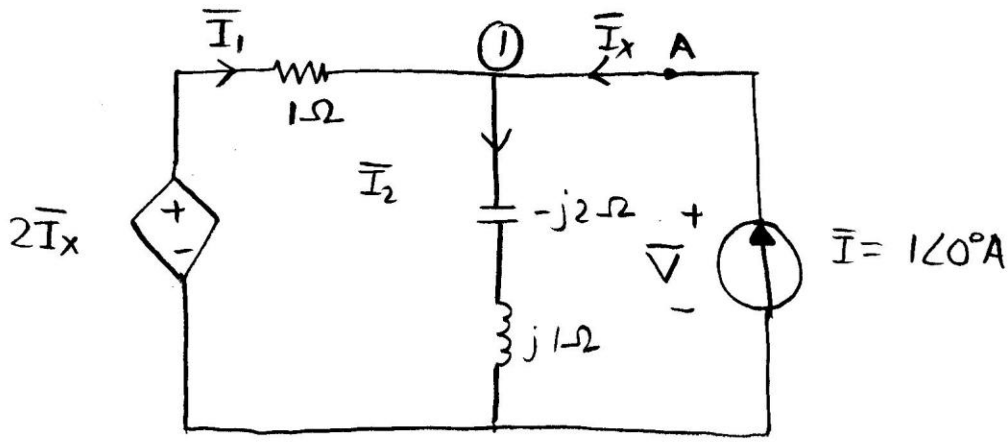


Figure P8.115

SOLUTION:



$$\bar{I}_x = \bar{I} = 1\angle 0° A$$

KCL at 1 : $\bar{I}_1 + \bar{I}_x = \bar{I}_2$

$$\frac{2\bar{I}_x - \bar{V}_1}{1} + 1\angle 0° = \frac{\bar{V}_1}{-j1}$$

$$-j1\left[2(1\angle 0°) - \bar{V}_1\right] - j1(1\angle 0°) = \bar{V}_1$$

$$\bar{V}_1 (1 - j1) = -j1(2)(1\angle 0^\circ) - j1(1\angle 0^\circ)$$

$$\bar{V}_1 = 2.12 \angle -45^\circ \text{ V}$$

$$\bar{V} = \bar{V}_1 = 2.12 \angle -45^\circ \text{ V}$$

$$\bar{Z}_{eq} = \frac{\bar{V}}{\bar{I}} = \frac{2.12 \angle -45^\circ}{1\angle 0^\circ}$$

$$\bar{Z}_{eq} = 2.12 \angle -45^\circ \ \Omega$$

$$\bar{Z}_{eq} = 1.5 - j1.5 \ \Omega$$

8.123 Use both a nodal analysis and a loop analysis, each in conjunction with MATLAB, to find $\mathbf{I}_o$ in the network in Fig. P8.123.

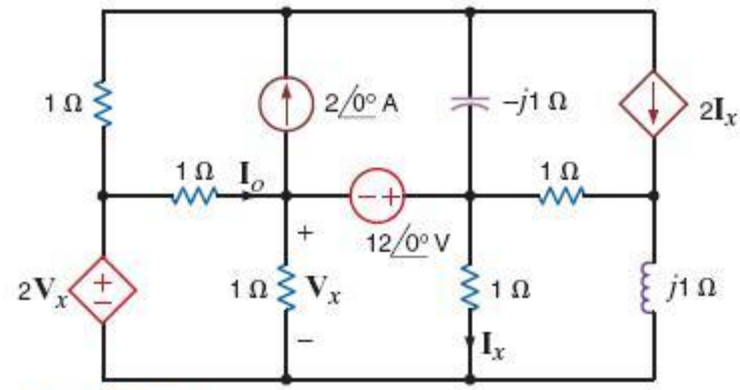
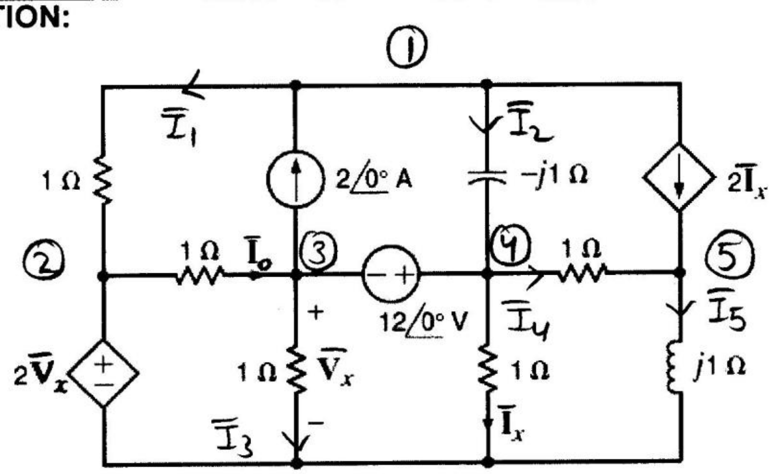


Figure P8.123

SOLUTION:



KCL at 1: $\bar{I}_1 + \bar{I}_2 + 2\bar{I}_x = 2\angle 0^\circ$

$$\frac{\bar{V}_1 - \bar{V}_2}{1} + \frac{\bar{V}_1 - \bar{V}_4}{-j1} + 2\left[\frac{\bar{V}_4}{1}\right] = 2\angle 0^\circ$$

$$-j1(\bar{V}_1 - \bar{V}_2) + \bar{V}_1 - \bar{V}_4 - j2\bar{V}_4 = -j1(2\angle 0^\circ)$$

$$(1 - j1)\bar{V}_1 + j1\bar{V}_2 + (-1 - j2)\bar{V}_4 = 2\angle -90^\circ$$

KCL at 5: $\bar{I}_4 + 2\bar{I}_x = \bar{I}_5$

$$\frac{\bar{V}_4 - \bar{V}_5}{1} + 2\left[\frac{\bar{V}_4}{1}\right] = \frac{\bar{V}_5}{j1}$$

$$j1(V_4 - V_5) + j2\bar{V}_4 = \bar{V}_5$$

$$j3\bar{V}_4 + (-1 - j1)\bar{V}_5 = 0$$

KCL at supernode:

$$\bar{I}_0 + \bar{I}_2 = 2\angle 0° + \bar{I}_4 + \bar{I}_x + \bar{I}_3$$

$$\frac{\bar{V}_2 - \bar{V}_3}{1} + \frac{\bar{V}_1 - \bar{V}_4}{-j1} = 2\angle 0° + \frac{\bar{V}_4 - \bar{V}_5}{1} + \frac{\bar{V}_4}{1} + \frac{\bar{V}_3}{1}$$

$$-j1(\bar{V}_2 - \bar{V}_3) + \bar{V}_1 - \bar{V}_4 = 2\angle 0(-j1) - j1(\bar{V}_4 - \bar{V}_5) - j1\bar{V}_4 - j1\bar{V}_3$$

$$\boxed{V_1 - j1\bar{V}_2 + j2\bar{V}_3 + (-1 + j2)\bar{V}_4 - j1\bar{V}_5 = 2\angle -90°}$$

$$\bar{V}_2 = 2\bar{V}_x$$

$$\bar{V}_2 = 2[\bar{V}_3]$$

$$\bar{V}_2 - 2\bar{V}_3 = 0$$

$$-\bar{V}_3 + \bar{V}_4 = 12\angle 0°$$

$$(1 - j1)\bar{V}_1 + j1\bar{V}_2 + (-1 - j2)\bar{V}_4 = 2\angle -90°$$

$$j3\bar{V}_4 + (-1 - j1)\bar{V}_5 = 0$$

$$\bar{V}_2 - 2\bar{V}_3 = 0$$

$$-\bar{V}_3 + \bar{V}_4 = 12\angle 0°$$

$$\bar{V}_1 - j1\bar{V}_2 + j2\bar{V}_3 + (-1+j2)\bar{V}_4 - j1\bar{V}_5 = 2\angle -90°$$

$$\bar{V}_1 = 7.11\angle 140.7° \text{ V}$$

$$\bar{V}_2 = 35.38\angle -137.3° \text{ V}$$

$$\bar{V}_3 = 17.7\angle -137.3° \text{ V}$$

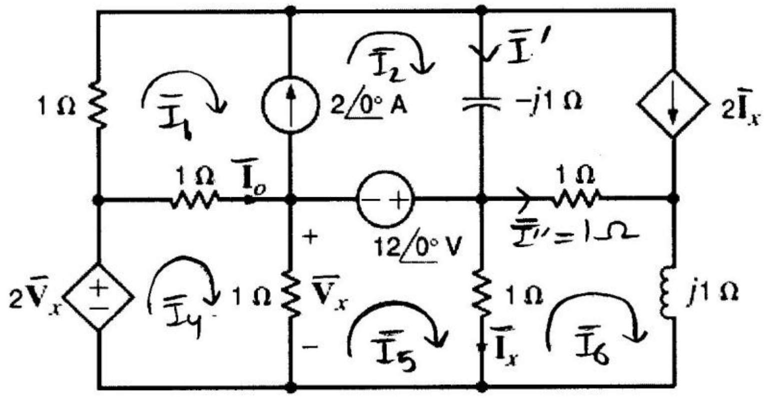
$$\bar{V}_4 = 12.04\angle -94.8° \text{ V}$$

$$\bar{V}_5 = 25.54\angle -49.8° \text{ V}$$

$$\bar{I}_o = \frac{\bar{V}_2 - \bar{V}_3}{1}$$

$$= \frac{35.38\angle -137.3° - 17.7\angle -137.3°}{1}$$

$$I_o = 17.7\angle -137.3° \text{ A}$$



KCL: $\bar{I}_5 + \bar{I} = \bar{I}_4$

$\bar{I} = \bar{I}_4 - \bar{I}_5$

KCL: $\bar{I}_3 + \bar{I}'' = \bar{I}_6$

$\bar{I}'' = \bar{I}_6 - \bar{I}_3$

KCL: $\bar{I}_4 = \bar{I}_1 + \bar{I}_0$

$\bar{I}_0 = \bar{I}_4 - \bar{I}_1$

KCL: $\bar{I}_2 = \bar{I}' + \bar{I}_3$

$\bar{I}' = \bar{I}_2 - \bar{I}_3$

KCL: $\bar{I}_x + \bar{I}_6 = \bar{I}_5$

$\bar{I}_x = \bar{I}_5 - \bar{I}_6$

KVL: $1(\bar{I}_0) + 1(\bar{I}) = 2\bar{V}_x$

$$\bar{V}_x = \bar{I}(1) = \bar{I}_4 - \bar{I}_5$$

$$\bar{I}_4 - \bar{I}_1 + \bar{I}_4 - \bar{I}_5 = 2(\bar{I}_4 - \bar{I}_5)$$

$$\boxed{-\bar{I}_1 + \bar{I}_5 = 0}$$

KVL: $1(-I) + 1(\bar{I}_x) = 12\angle 0°$

$$(\bar{I}_4 - \bar{I}_5) + \bar{I}_5 - \bar{I}_6 = 12\angle 0°$$

$$\boxed{-\bar{I}_4 + 2\bar{I}_5 - \bar{I}_6 = 12\angle 0°}$$

KVL: $1(I'') + j1(\bar{I}_6) + 1(-\bar{I}_x) = 0$

$$\bar{I}_6 - \bar{I}_3 + j1\bar{I}_6 - (\bar{I}_5 - \bar{I}_6) = 0$$

$$\boxed{-I_3 - I_5 + (2+j1)\bar{I}_6 = 0}$$

KCL: $\bar{I}_1 + 2\angle 0° = \bar{I}_2$

$$\boxed{\bar{I}_1 - \bar{I}_2 = -2\angle 0°}$$

$$\bar{I}_3 = 2\bar{I}_x$$

$$\bar{I}_3 = 2(\bar{I}_5 - \bar{I}_6)$$

$$\boxed{\bar{I}_3 - 2\bar{I}_5 + 2\bar{I}_6 = 0}$$

$$KVL: \; 1(\bar{I}_1) - j1\bar{I}' + 12\angle 0° + 1(-\bar{I}_0) = 0$$

$$\bar{I} - j1(\bar{I}_2 - \bar{I}_3) + 12\angle 0° - \bar{I}_4 + \bar{I}_1 = 0$$

$$\boxed{2\bar{I}_1 - j1\bar{I}_2 + j1\bar{I}_3 - \bar{I}_4 = -12\angle 0°}$$

$$-\bar{I}_1 + \bar{I}_5 = 0$$

$$-\bar{I}_4 + 2\bar{I}_5 - \bar{I}_6 = 12\angle 0°$$

$$-\bar{I}_3 - \bar{I}_5 + (2+j1)\bar{I}_6 = 0$$

$$\bar{I}_1 - \bar{I}_2 = -2\angle 0°$$

$$\bar{I}_3 - 2\bar{I}_5 + 2\bar{I}_6 = 0$$

$$2\bar{I}_1 - j1\bar{I}_2 + j1\bar{I}_3 - \bar{I}_4 = -12\angle 0°$$

$$\bar{I}_1 = 35.11\angle -125.73° \text{ A}$$

$$\bar{I}_2 = 34\angle -123° \text{ A}$$

$$\bar{I}_3 = 24.1\angle -94.8° \text{ A}$$

$$\bar{I}_4 = 52.56\angle -129.6° \text{ A}$$

$$\bar{I}_5 = 35.11\angle -125.73° \text{ A}$$

$$\bar{I}_6 = 25.54\angle -139.8° \text{ A}$$

$$\bar{I}_0 = \bar{I}_4 - \bar{I}_1$$

$$\bar{I}_0 = 52.56 \angle -129.6° - 35.11 \angle -125.73°$$

$$\bar{I}_0 = 17.7 \angle -137.3° \text{ A}$$

MATLAB Solution:

```
Y= [1-i i 0 -1-2i 0;0 0 0 3i -1-i;0 1-2 0 0;0 0-1 1 0; 1-i 2i -1+2i -1]

I = [-2i; 0; 0;12;-2i;]

V= inv(Y)*I

IO= V(2)-V(3)/1

% Answer:
  Y=

    Columns 1 through 3
  1.0000 -1.0000i       0+1.0000i          0
       0                0                  0
       0           1.0000            -2.0000
       0                0            -1.0000
  1.0000                0-1.0000i    0+2.0000i
    Columns 4 through 5
  -1.0000-2.0000i              0
        0+3.0000i      -1.0000-1.0000i
        0                      0
  1.0000                       0
  -1.0000+2.0000i      0-1.0000i
```

I =

0 - 2.0000i
0
0
12.0000
0 - 2.0000i

V =

-5.5000 + 4.5000i
-26.0000 - 24.0000i
-13.0000 - 12.0000i
-1.0000 - 12.0000i
16.5000 - 19.5000i

IO =

-13.0000 - 12.0000i

8.126 The network in Fig. P8.126 operates at $f = 60$ Hz. Use PSPICE to find the voltage $\mathbf{V}_o$.

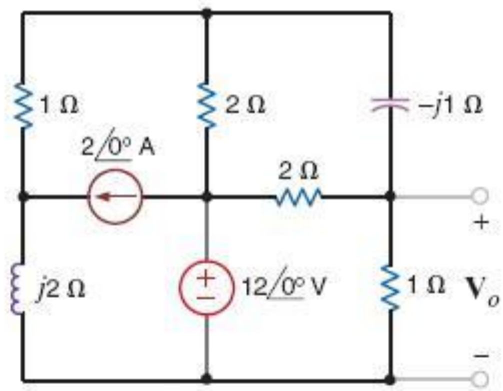
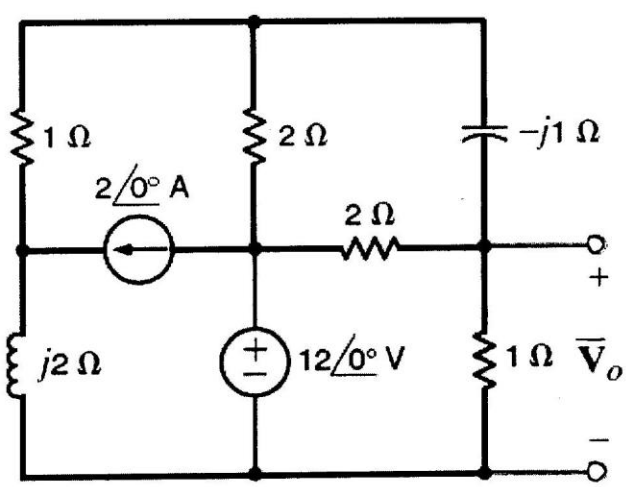


Figure P8.126

SOLUTION:



$F = 60\ \text{Hz}$, $\omega = 377\ \text{rad/s}$

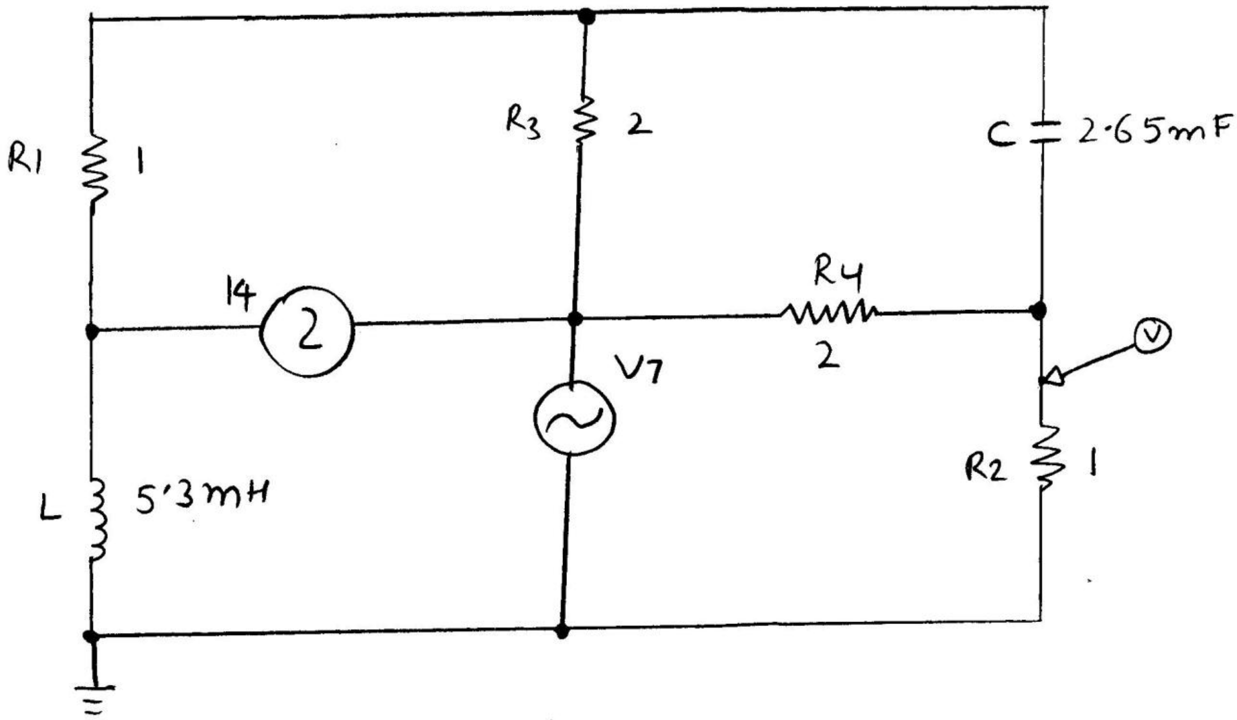
$\bar{Z}_L = j\omega L$

$$L = \frac{\bar{Z}_L}{j\omega} = \frac{j2}{j(377)} = 5.3\ \text{mH}$$

$\bar{Z}_C = \dfrac{1}{j\omega C}$

$$C = \frac{1}{j\omega \bar{Z}_c} = \frac{1}{j(377)(-j1)}$$

C= 2·65 mF



PSPICE Schematic Diagram

**** AC ANALYSIS

****

FREQ	VM($N_0004)	VP($N_0004)
6.000E+01	4.368E+00	1.018E+01